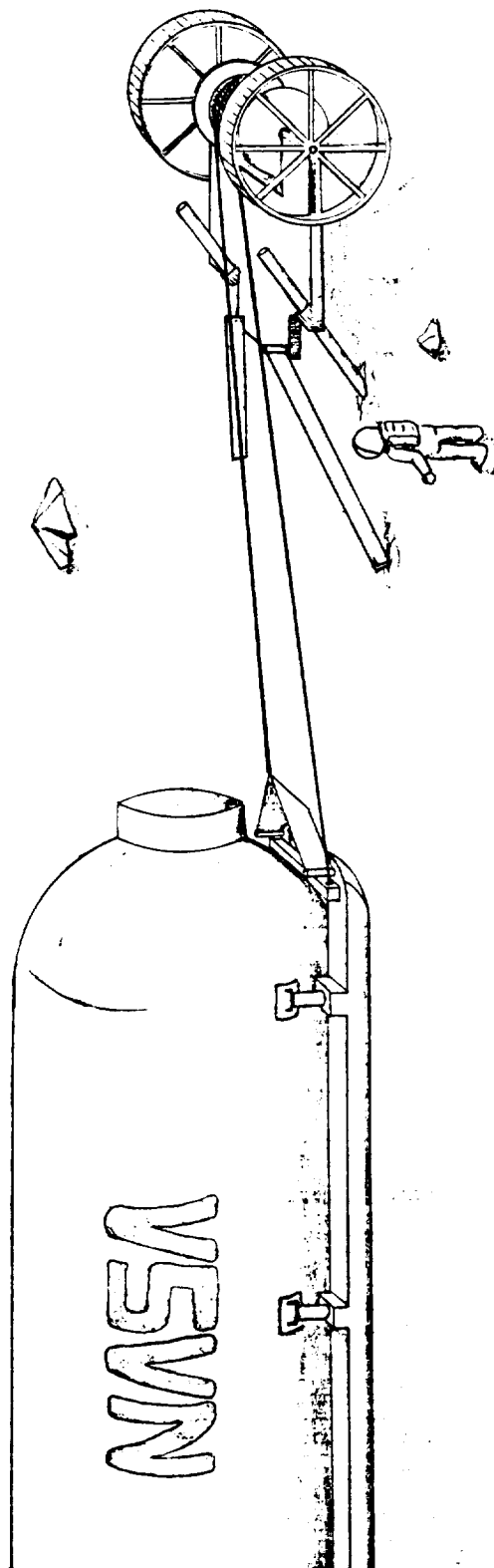




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(NASA-CR-197147) EXTERNAL DEVICE
TO INCREMENTALLY SKID THE HABITAT
(E-DISH) (Georgia Inst. of Tech.)
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D evice to
I ncrementally
S kid the
H abitat

**Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, Georgia**

EXTERNAL DEVICE TO INCREMENTALLY SKID THE HABITAT (E - DISH)

**Georgia Institute of Technology
School of Mechanical Engineering
Atlanta, Georgia**

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Steve Introne**

Lisa Bedell, Ben Credle, Graham Holp, Siao Ly, Terry Tait

Abstract

Group Four of Mechanical Design ME 4182 has designed a Mars habitat transport system for submission to NASA as part of their Mars exploration program. The transport system, the External Device to Incrementally Skid the Habitat (E - DISH), will be used to transport Mars habitats from their landing sites to the colony base and will be detached after unloading. The system requirements for Mars were calculated and scaled for model purposes. Specified model materials are commonly found and recommendations for materials for the Mars design are included.

Introduction

In establishing a Mars colony, several modular habitat units will be brought separately to the planet where they will be connected together. The first habitat will be placed at the initial landing site. However, subsequent landings will be far away from the colony so as not to risk colony damage. Therefore a device is needed to transport the habitat modules from their landing sites to the colony site and orient them for connection.

A transport system for NASA Mars exploration program was designed by Group Four of Mechanical Design ME 4182 during the Fall quarter of 1993. The External Device to Incrementally Skid the Habitat (E-DISH) was governed by the constraints and requirements of the Mars terrain and design parameters.

Requirements and Assumptions

The following requirements were dictated by the design parameters and the Mars terrain; the transport device must:

- transport one 50 metric ton hemispherical ended habitat cylinder of dimensions 5m diameter and 15m length
- transport a cylinder a distance of 500-1000m

- be able to climb over obstacles 1m in height, cross crevasses 1m wide, and not tip over in the transport process
- provide protection for the habitat so that no damage is incurred.

Further requirements and constraints were defined by the design team and are as follows:

- the habitat cylinder will have six hard points included for attachment to the transport device
- a total transit time of 1 hour
- the device must survive the Martian environment
- any acceleration of the habitat by the device is assumed to be much less than the launching acceleration from Earth
- the device must weigh no more than 17,500 kg, fit within the space shuttle cargo bay, and be easily assembled.

Basic Operation

E-DISH is a system comprised of a skid, a powered increment, and a separate cone alignment device. The skid is a framework of supports mounted on skis with the powered increment taking after a military cannon design. The alignment cone is a hinged device which acts as a guide in connecting two habitats.

The device decided upon through design matrices and considering Mars physical properties was the skid with a powered increment. The need to design a suspension system to overcome the obstacles of the Mars terrain was avoided by the use of the incremented skid. This skid can maneuver around the obstacles in its path of travel. The basic operation is as follows:

1. The habitat is loaded onto the positioned skid.
2. The skid is attached to the increment with the two cables. The increment is driven the first 100 meters of the distance to the colony site. The increment stops and anchors itself into

- the ground using the augers. The increment pulls the loaded skid to its new position.
3. The process continues until the habitat is within 20 meters of the base.
 4. An alignment cone is attached to the initial habitat and the skid cable strung through its pulley system.
 5. The increment is driven to the rear of the habitat to pull the habitat into connection.
 6. The skid stays under the habitat until the habitat is within one meter of the initial habitat. The power screws are retracted to lower the habitat. When the habitat is resting on the ground, the front cross brace and the shield are removed. The increment then pulls the habitats together.
 7. The increment is used to pull the skid backwards out from under the habitat and the alignment cone is detached.

Component Designs

E-DISH is divided into three subsystems: a powered increment, a skid, and a connection device, with components to each subsystem.

Powered Increment

The increment is the powerhouse of the design with three motors, two for the wheels and cable drum and a third for the augers. The following is a detailed break-down of its components.

Frame. The model frame is made of 6061-T6 aluminum for strength and ease of machining. The frame material is important in that all other components are attached to it.

Cable Drum. Two cables were chosen to maximize the strength to the weight. Using Machinery's Design Handbook¹, the actual Mars cables are type 6 x 19 improved plow steel wire rope, 2.22cm in diameter, and 100m in length to withstand a tension of 153 kN. The cable drums have drum diameters of 1m, drum widths of 0.58m, and flange diameters of 1.18m. The tension dictates that the cable drums be made of 6061 T6 aluminum of 270 MPa² yield strength to withstand a radial pressure of 13.8 kPa.

For the model, 8 lb DuPont Stren fishing line is used for the wire rope to pull a load of 1.5kg and the drum material is 6061-T6 aluminum. The model drum is of dimensions R18 x 30mm.

Clutch System. The two major operations of the powered increment are driving to the colony base from the habitat's landing site and pulling the loaded skid. Power must be independently supplied to both the wheel and cable drum systems to allow proper wheel operation and cable release. The clutch design allows the wheels to be engaged

with the cable drum in neutral so as to spool out cable as it is being driven. When the cable drum is engaged, the wheel system must be locked out to prevent increment movement.

The clutch system incorporates the square jaw type clutch with the benefits of a self aligning cone clutch. Clutch limitations due to the temperature gradients of Mars and the high possibility of clutch wear eliminate friction based clutch systems. Using the square jaw clutch allows for positive engagement with no slippage due to the interlocking mated components. A six spline star pattern as shown in Figure 1 was chosen to distribute the applied torque evenly through out the mated component.

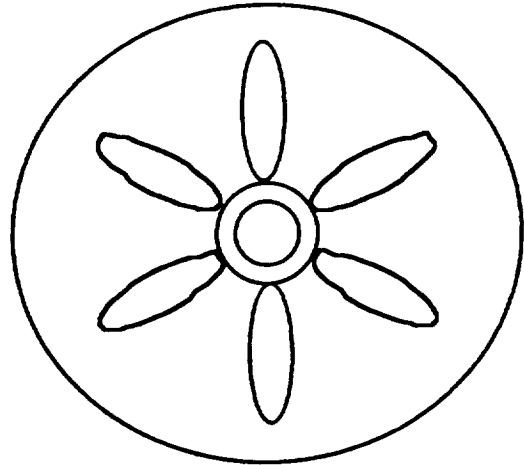


Fig. 1 Six spline star pattern

No clutch holding force is required to hold the mating components in position since the mating splines are parallel to the mated spline slots. An engaging force of 24N is needed for the model and 980N for the actual Mars design.

To reduce engagement shock known to positive engagement clutch systems, the mated component was designed with self-aligning slopes. The guide slopes combine with the "free" travel of the clutch to mate the splines without jamming. The mating component was designed with a twelve spline pattern to reduce the amount of travel needed. Splines are set 30° apart with the slope peaks at 15° from the spline center. The aligning slope angle of 27° from horizontal in Figure 2 gives the best guidance with the shortest height without engagement shock occurring.

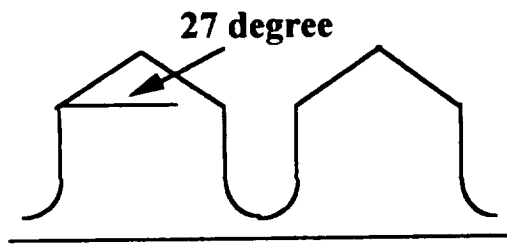


Fig. 2. Aligning slope angle

Axles. The wheel and cable drum systems share a central axle. This reduces the total weight and increases the stability of the increment since the cable drum under full tension would require a large support system and the center of gravity is lowered by this configuration. The clutch system is mounted on a secondary axle that is designed to slide back and forth through the main frame. Aluminum tubing of OD 7mm, ID 5mm with Teflon lubrication is used for the model. An axial rated bearing system must be used for the actual Mars design. This system uses bearings parallel to the axles to allow for parallel movement.

The main axle consists of a 6061-T6 aluminum shaft and is milled in three sections from R3.0mm to R2.5mm to R2.0mm. The smallest section provides a mount for the wheel. An axle cap secures each wheel to the axle.

Powertrain. The need for reliable and reversible high output energy sources is required for the E-DISH. A high power output is needed to drive the increment wheels and to pull the loaded skid. The model power source chosen was the Tamiya 1000 rpm model electric motor. The motors are capable of pulling 3kg with gear reductions as shown in Figure 3 achieved through two 24mm double diameter spur gears and two small 5mm alignment spur gears. This geartrain is connected to a 15mm spur gear on the main axle so as to never disengage from each other. This is essential since the main axle gear travels 7mm and if disconnected could cause the increment to go off-line.

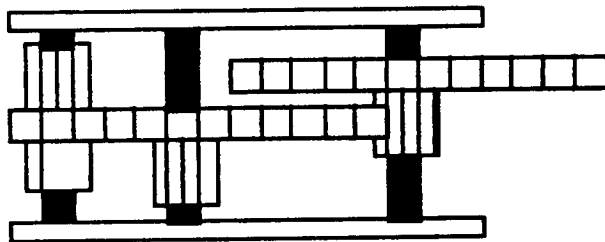


Fig. 3. Geartrain configuration

The motors are cost effective, easily replaced, and compact for mounting. Three "C" size batteries are needed to power three motors, wired such that two motors are always connected while the third is wired in a connect / disconnect manner. This eliminates the need for additional batteries.

The motors are mounted to the bottom of the increment frame to maximize space. The mount is a "U"-shaped strip of aluminum with the bottom cut out creating a frame-like structure to reduce weight. Shaft openings are cut into the side of the mount. The gear mount is a similar one piece design with the shaft openings cut out of the sides. The gears are attached to the shafts with glue.

For the Mars design, electric motors that produce a minimum torque of 5.7 kN-m are required. Variable speed specification is also important to reduce start up shock. Battery sources are still a subject for research. As of today's technology, they will require the most component space and add the most weight to the increment assuming they are to be solar rechargeable with standard electric voltage outputs.

Augers and Legs. In order to secure the increment while winching the skid, two augers of 6061-T6 aluminum (model and actual design), one on each side at the rear of the increment, are used to anchor into the soil along with support legs with blades.

The support system is designed with 66% of the resistant force on the augers and 33% on the support leg blades.

The two augers are positioned so as not to interfere with motor operation and have sufficient ground clearance. They are set at -45° from the horizontal to minimize depth for the greatest holding strength. This reduces the shear stress on the actual auging shaft and offers the greatest resistive force. The augers are placed behind the main axle/frame connection to give a direct opposing force to the tension, helping to reduce the bending stress on the main axle. The auger blades screw into the terrain so as not to remove the soil above it. Maximum soil compression is achieved resulting in higher resistive forces to the cable tension.

The auger system includes one reversible 1000 rpm motor that uses bevel and spur gears to operate the auging system. The augers are rotated through the use of a bevel/spur gear connection. This connection drives a chain to the outside spur gear. This outside spur gear drives the main auger bevel gear in which the auging device floats up and down. To raise and lower the auger a secondary bevel/spur gear is used. The main bevel gear off the motor drives a second spur gear which turns the support shaft. On each end of this shaft, a spur gear is engaged to the auging device. This raises or lowers the auger. The power supply may be turned off when the augers are not in use so as to conserve battery power.

An alternative design for possible consideration involves changing the auger spinner system, the chain driven bevel/spur gear connections, to a one shaft design incorporating a hypoid spur gear connection as shown in Figure 4. The hypoid gear drives the main bevel gear while the spur gear raises and lowers the auger. Due to time constraints and the lack of dimensions for the main bevel gear, a hypoid gear was not designed.

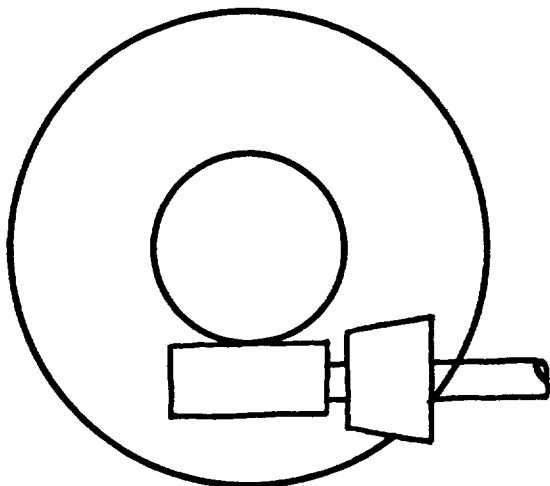


Fig. 4. Possible hypoid gear configuration

The support legs provide the maximum strength with the lightest weight, such as I-beams or T-beams with a cross sectional area of $5.5 \times 10^{-4} \text{ m}^2$ made of 6061-T6 aluminum (model and actual design material). The two legs are connected to the main frame by a pin connection that allows the legs to be swung in or out for storage and/or transport. The connection position is directly in line with the cable drum connection to the clutch. This gives the maximum resistance to the cable tension. Blades are welded onto the end of the legs offering a resistance force by burying into the soil when the increment is pulling the loaded skid.

Wheels. The wheels for the powered increment are a one piece unit of 6061-T6 aluminum with a secondary traction layer. The wheel consists a central hub with eight ribs supporting the exterior ring with an outer diameter of 76mm. To increase the strength of the wheel ribs, the wheel accepts the mated component of the clutch as an integral part. This clutch component increases the strength and reduces the chance of rib bending or failure when welded to the main hub. The secondary layer is made of soft rubber and is pre-molded so as to attach to the outer ring of the wheel. Ground clearance on the model scale is 12mm but for the actual design the wheel diameter is variable upon terrain requirements.

Skid Design

The skid consists of two skis joined by two crossbeams. The habitat module is attached by six hard points placed according to an assumed habitat fuselage³ to height adjustable support members. The maximum ground clearance of the module is 7.9mm. The front of the habitat is protected by a cow-catcher type shield. All major parts are made of 6061-T6 aluminum due to its superior strength-to-

weight ratio. This is the model material as well as the actual Mars skid. Model dimensions given can be scaled by 39.37 to calculate actual dimensions. The skid is pulled by two removeable cables attached to the front cross brace. The skid is 381mm long and 102mm wide, slightly narrower than the habitat (assuming 127mm habitat diameter) in order to minimize weight without compromising stability. The loaded skid can traverse a 35° side hill without tipping. This stability allows one ski of the skid to run over a 2.3 meter rock at Mars specifications without tipping over. The loaded skid will begin sliding due to gravity on a down slope between 17° and 35°. The exact angle depends on the friction coefficient of the particular terrain, which is estimated to be between 0.3 and 0.74. Current weight estimates for the skid are about 10.3 metric tons, or about 20% of module mass. The actual Mars skid will sink no more than 3 cm into the soil when fully loaded.

Ski Design. Each ski is 369mm long and 13mm wide x 6.5mm high (Figure 5).

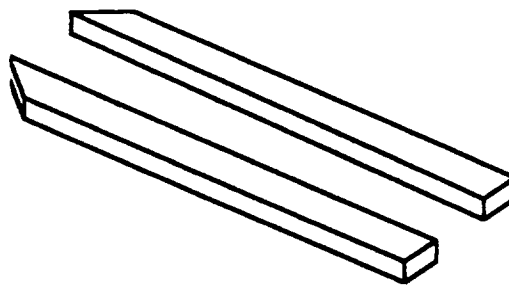


Fig. 5. Skid skis

Both the front and rear ends of the skis are upcurved to ease sliding, and the bottom surface is hemi-cylindrical. Using a Martian soil bearing capacity of $3.5 \text{ N/cm}^2/\text{cm}^5$, the skis should sink no more than 3cm into the soil. This results in a contact patch of 0.22m wide for each ski. The ski bottoms are coated with Teflon to decrease sliding friction. Research indicates that a Teflon coating can reduce the coefficient of sliding friction in similar applications^{6,7}.

Cross Braces. The cross braces are 3.5mm x 3.5mm in cross section and 89mm long. This cross section insures that each support can safely support the habitat in the maximum load condition of a 35° side hill. The length determines the spacing between the skis. Both braces are removable for easier space transport of the skid, but when in service, the rear brace is permanently attached. The front brace is removed prior to unloading the habitat from the skid so that the skid may be pulled out from under the module.

Supports. Each of the six support posts contain a power screw (Figure 6) capable of raising and lowering the habitat for connection to the colony base habitat.

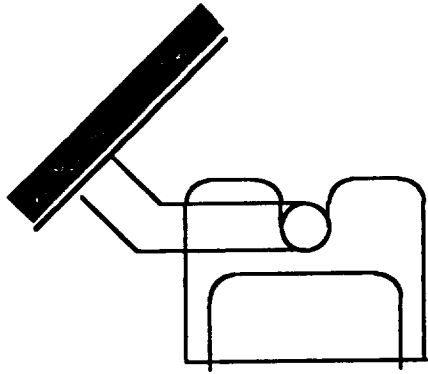


Fig. 6. Floating head for hard points to habitat

The module is raised during transport to provide maximum ground clearance. When the colony site is reached, the habitat module is lowered to the ground and the skid is pulled out from the rear. The connection site between the support and the module was chosen to intersect the module in such a way that all forces on the module are radial.

Shield. The shield is a one piece design made of 6061-T6 aluminum which is completely removed during the unloading of the habitat. It is 7.5mm tall and 1mm thick with a 7.9mm ground clearance, same as the habitat, to allow small rocks to pass beneath it.

Connection Device

A cone-like device is needed to facilitate alignment of the new habitat to the existing module. To minimize the weight of the structure, the connection/alignment is a wire frame structure (Figure 7) consisting of 6061-T6 aluminum tubing for the actual Mars design.

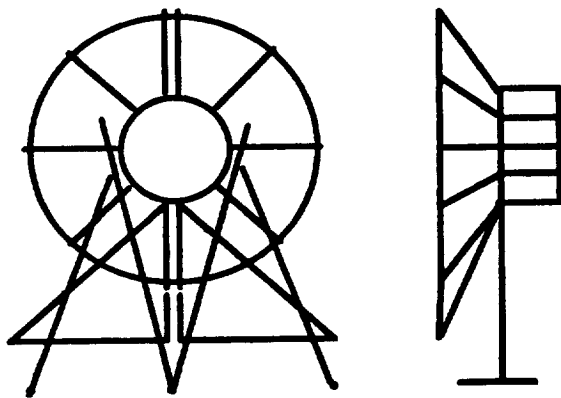


Fig. 7. Alignment Cone

The alignment must be able to withstand an impact force where the habitat might bang the structure. The impact

force is dependent on the mass of the skid and its acceleration. The acceleration of the skid is assumed to be very small due to being pulled slowly into alignment, resulting in a negligible impact force. The considered forces are the stresses applied to the connection device from the module, possibility causing bending or buckling to the structure.

The model cone fits around a 26mm diameter connection seal. The composition of the cone consists of two hemispherical wire-frame halves, made of 4mm diameter carbon steel wire. The cables attached to the skid are redirected through a side support on the cone to the increment to allow clearance, preventing any contact between the cable and the module.

For the actual connection, a 50.8mm aluminum tube with wall thickness 5.5mm is used as the main material. The weight of the each cone half is estimated at 1650N. As for column buckling of the connection device over the seal, a critical force of 1000kN was calculated. Assuming an acceleration of 0.1m/s^2 , a force of 6500N was found to cause a deflection of 5mm on the bar, assuming all the forces from the skid is concentrated at one point. A 0.1m diameter pulley with grooved sides is used to redirect the cables, reducing friction between the cable and the cone device. Each pulley, along with the support, handles a tension force of at least 76.5N. The actual design allows for a 1m tolerance in aligning the habitats.

Concluding Remarks

Total System

The E-DISH meets the standards put forth by the opening problem statement. It transports the 50 metric ton habitat module over the required distance safely and efficiently. This system can be removed from the module and used repeatedly for additional modules. The weight of the system is 10.3 metric tons for the skid component, 0.2 metric tons for the alignment connection, and 6.5 metric tons for the increment. The overall system will require approximately one hour for transport time from the landing site to the colony base. This overall design fulfills the weight requirement in that it will be less than the weight of the module. This system has a better cost-to-benefit ratio than an integral transport system in that once the E-DISH has been transported to Mars, it can be used indefinitely without any additional space flight weight.

Further Recommendations

The control systems for the E-DISH include controls for the batteries, wheels, ground drills, cable drum, and power screws. Voltmeters are needed to monitor the batteries power level with warning lights and a master on / off switch.

The wheels are individually controlled, are reversible, and have variable speed settings. The ground drills have an on / off switch and are restricted to up and down movement. The cable drum has an on / off switch with warning lights for slack cable and clutch jam. These controls can be designed so that the entire system can be remotely controlled, requiring no extra-vehicular activity.

To help in driving the increment, a secondary free wheel that can be extended or withdrawn should be added to the support legs to the increment. This free wheel would raise the rear blades off the terrain, eliminating drag.

A braking system can be added to the skid so that steep down hills could be traversed which would otherwise have to be avoided. This addition could be as simple as flaps which would extend into the soil to increase drag.

References

- 1) Green, R.E., *Machinery's Handbook*, 24th ed., Industrial Press, Inc., 1988, pp. 325-334.
- 2) Gere, J.M., and Timoshenko, S.P., *Mechanics of Materials*, 3rd ed., P.W.-KENT, Boston, 1990, p. 780.
- 3) Megson, T.H.G., *Aircraft Structures for engineering students*, 2nd ed., Halstad Press, New York, 1990, p. 325.
- 4) Avallone, E.A., and Baumeister, T., *Mark's Standard Handbook for Mechanical Engineers*, 9th ed., McGraw-Hill, New York, 1987.
- 5) United States. National Aeronautics and Space Administration. Surface Models of Mars (1975) / National Aeronautics and Space Administration. NASA, Washington, D.C., 1975, p. 25.
- 6) Schreiner, B.G., Trafficability of Snow in Arctic and Subarctic Regions, Army Engineer Waterways Experiment Station, Vicksburg, Miss., March, 1965.
- 7) Gaffney, E.S., Measurements of Dynamic Friction Between Rock and Steel, Systems Science and Software, La Jolla, Calif., October 25, 1976.
- 8) Shigley, J.E., and Mischke, C.R., *Mechanical Engineering Design*, 5th ed., McGraw-Hill, New York, 1989.

Technical Appendix

Technical Drawings Table of Contents

Powered Increment

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Motor Mounts	PT.4
Main Axle Caps	PT.5
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Auger Gear	DL.2
Drill Bracket	SP.1
Support Legs	SP.2
Support Blades	SP.3
Support Pin	SP.4
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Alignment Cone

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Right Cone	C.2

Skid

Overall Skid View	S1
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Left Skid Ski	S2.2
Power Screw Head	S2.3
Skid Shield	S3
Front Crossbar	S4
Back Crossbar	S5

Addendum

1. Endflange:

Drill one (1), 2mm hole on each endflange. This hole is used to connect the cable to the cable drum. The hole should be placed as low to the drum as possible to help place the highest stress near the clutch/flange connection. This connection is where the component is the strongest. The change in inertia is negligible.

2. A battery storage device must be designed. This design is similar to the motor mount with the dimensions to match "C" size batteries. 25mm x 50mm.

3. Six (6) 2mm microscrews are needed for various connections. See drawings.

4. DuPont stren fishing line is the model for the cable. Model requires, two (2) lines that are one (1) meter in length.

5. Solder two (2) eye hooks onto the front crossbrace of the skid unit. Hooks are placed in a position that will not interfere with shield placement or operation.

6. Soft rubber traction tread is from Mattel's Field Battle Command Battle Tank, with remote. Cut off underside rubber fins and cut to fit to wheel circumference. Two (2) treads are required.

General Notes:

1. All aluminum components are of 6061 T6 Aluminum type.
2. All corners to be filleted, rounded, or smoothed.
3. Verify all dimensions and clearances before construction.
4. Scale on drawings when referring to 1/8=1, mm is plotting reduction factor, components are dimensioned as marked on drawings. All drawings have base limits of 11x17.

Specified Components:

1. Shafts and quantity needed:
 - a. diameter=2mm, length=11mm, 2
 - b. diameter=2mm, length=11mm, 2
 - c. diameter=2mm, length=11mm, 2
 - d. diameter=2mm, length=71mm, 1

2. Gears and quantity needed:

- a. Lago's DD=5mm spur gear, length=7mm, 2
- b. Matel's Field Command Battle Tank, with remote, DD=24 spur gear, 2
- c. Matel's Field Command Battle Tank, with remote, DD=24 spur gear, 2
- d. Matel's Field Command Battle Tank, with remote, DD=5mm spur gear, 2
- e. Lego's 4 wheeler, bevel gear with modifications, See 1/DL.2
- f. Lego's 4 wheeler, spur gear, 2
- g. Lego's 4 wheeler, small spur gear, 2
- h,i,j. Lego's helicopter, rotor system, 1 each.
- k. Lego's helicopter, spur gear, DD=15mm, 2

3. Solinoid is RC model type.

4. Controls are available at Radio Shack

Component Sheet

Overall top	G1
Tech top	Gl.1
Overall side	G2
Frame	FM.1
Wheel	Wh.1
Secondary Axle	Wh.2
Cable Drum	CD.1
Centerflange	CD.2
End flange	CD.3
Motor	PT.1
Gearmount	PT.2
Mainaxle	PT.3
Motor mount	PT.4
Axle caps	PT.5
Auger	DL.1
Auger gear	DL.2
Drill brackets	SP.1
Support Legs	SP.2
Support Blades	SP.3
Support Pin	SP.4
Blade caps	SP.5
Mating clutch	CL.1
Clutch control	CS.1

General Information

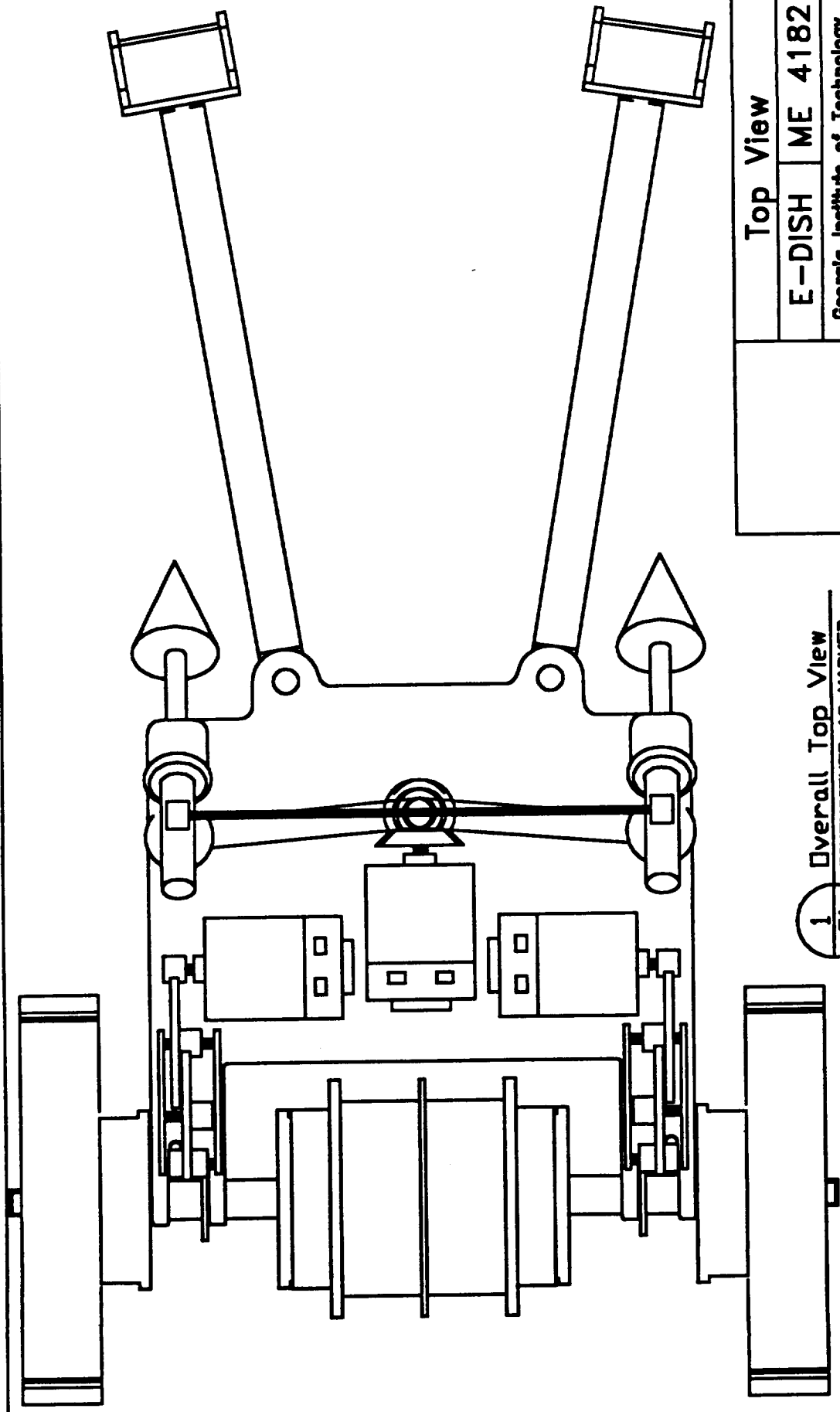
E-DISH ME 4182

Georgia Institute of Technology

DWN BY: GRAHAM HOLP

SCALE: No scale

GEN



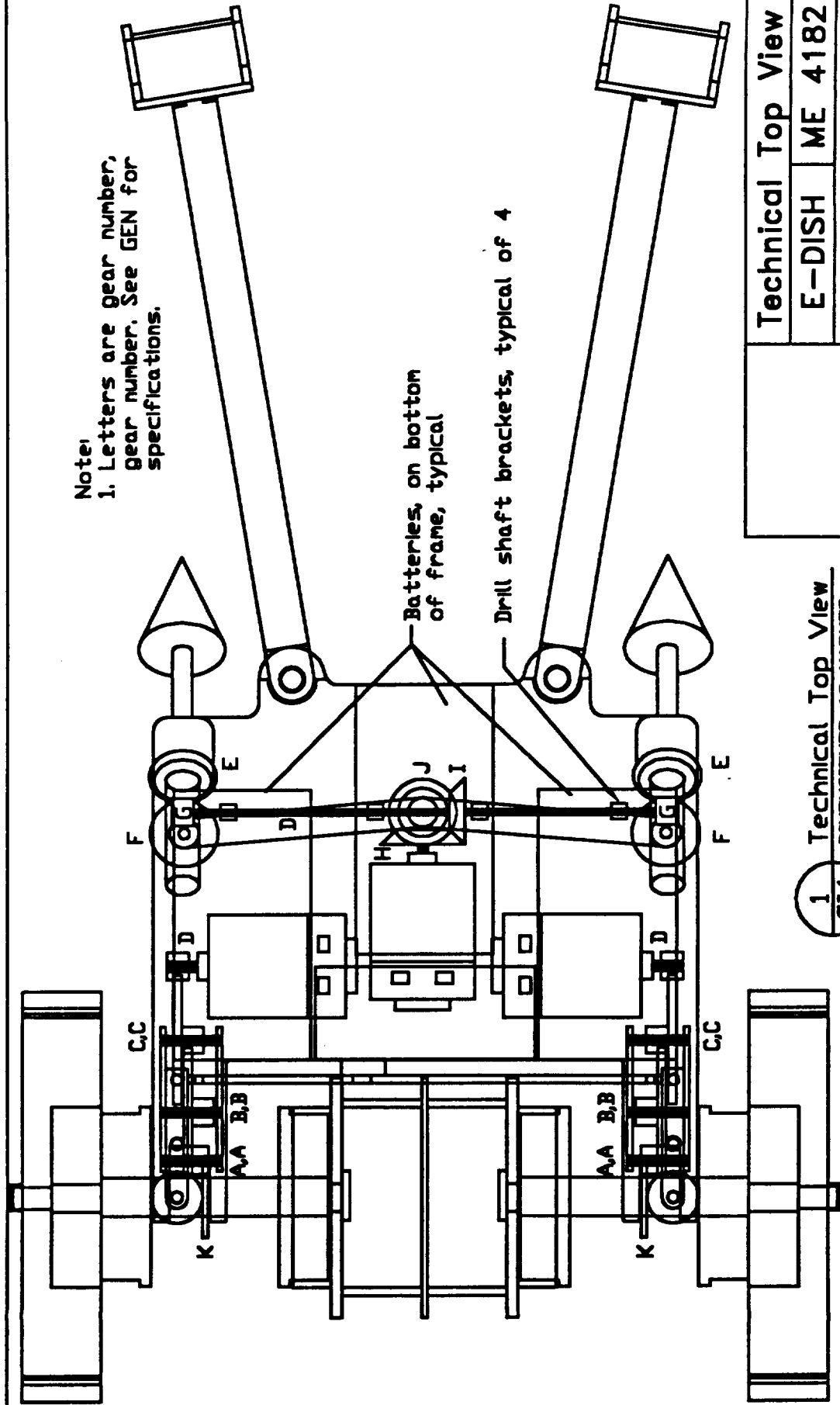
Top View

E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	
SCALE: SEE DWD, 1/32, MM	

G1

1 Overall Top View
G1 DIMENSIONED AS MARKED

Note:
1. Letters are gear number,
gear number. See GEN for
specifications.

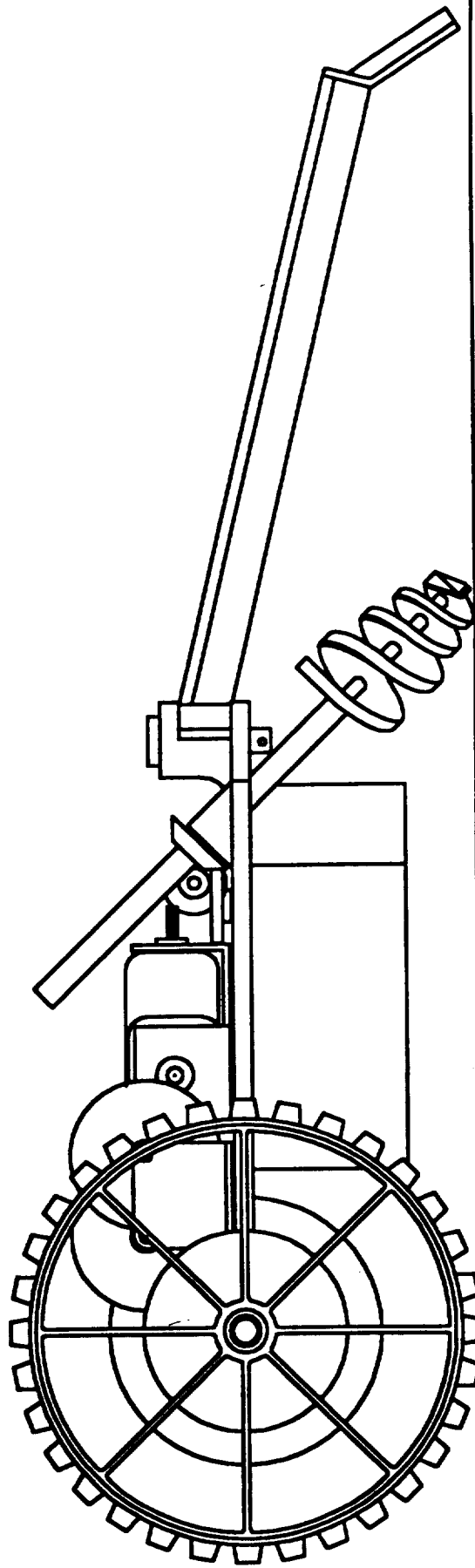


Batteries, on bottom
of frame, typical

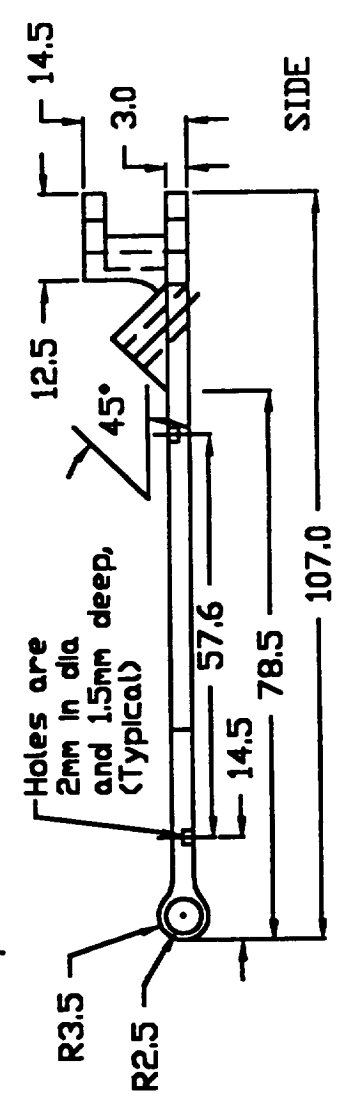
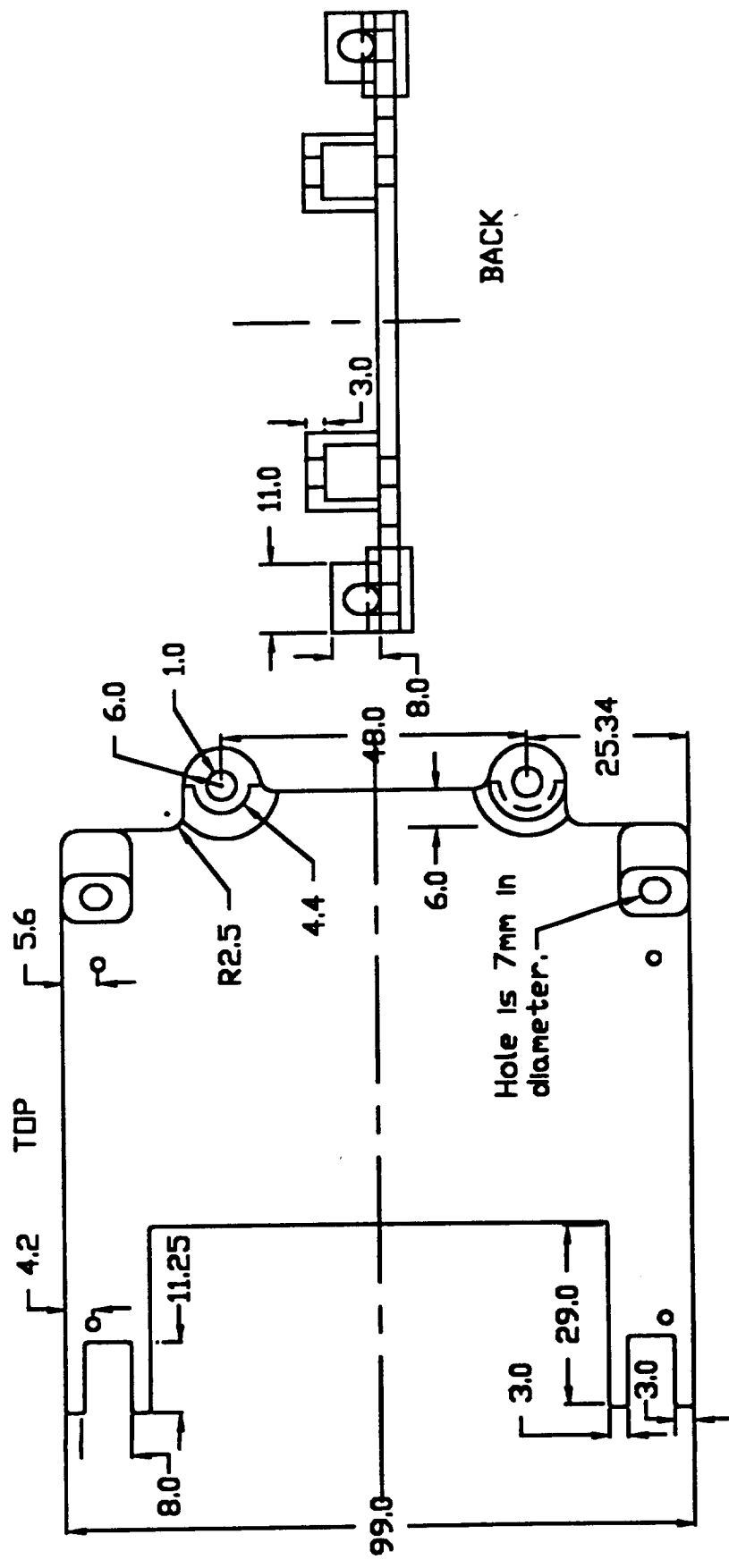
Drill shaft brackets, typical of 4

1 Technical Top View
GL.1 DIMENSIONED AS MARKED

Technical Top View	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	
SCALE: SEE DWO, 1/32, MM	
GL.1	

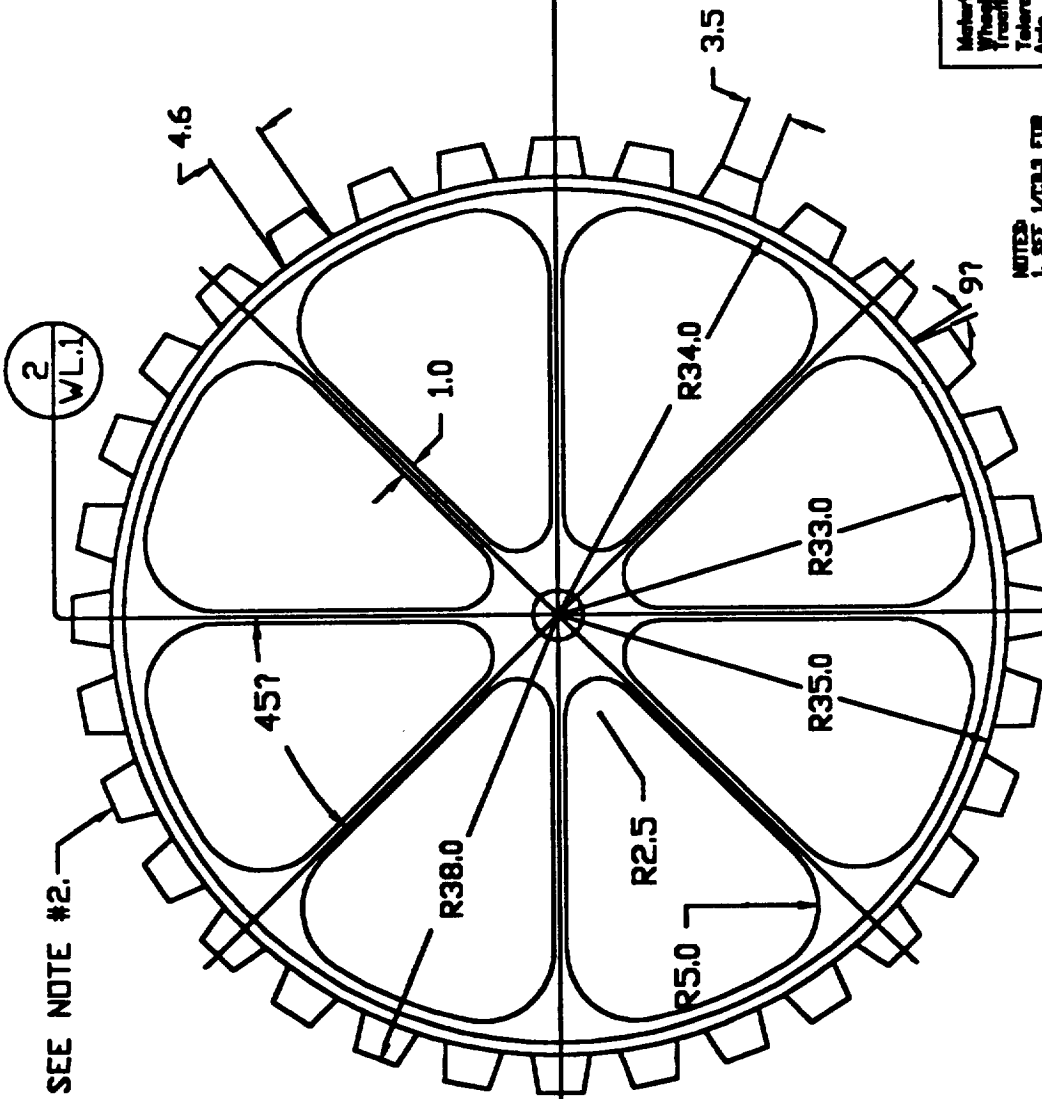


Overall Side View		
E-DISH	ME	4182
Georgia Institute of Technology		
DWN BY: GRAHAM HOLP		G2
SCALE: SEE DWG, 1/32, MM		



Material:
9041 TR
Aluminum
Tolerances
General, ± 0.08
Quantity: 1

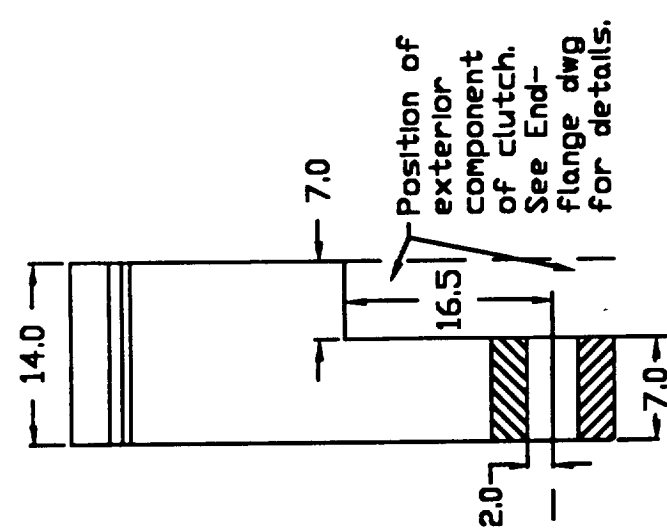
Frame	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	FM.1
SCALE: SEE DWG, 1/8=1, mm	



SEE NOTE #2.

1 MAIN WHEEL
WH.1
DIMENSIONED AS MARKED

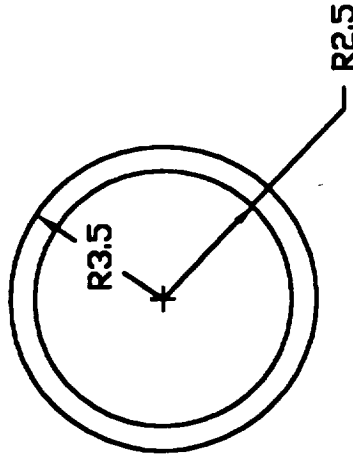
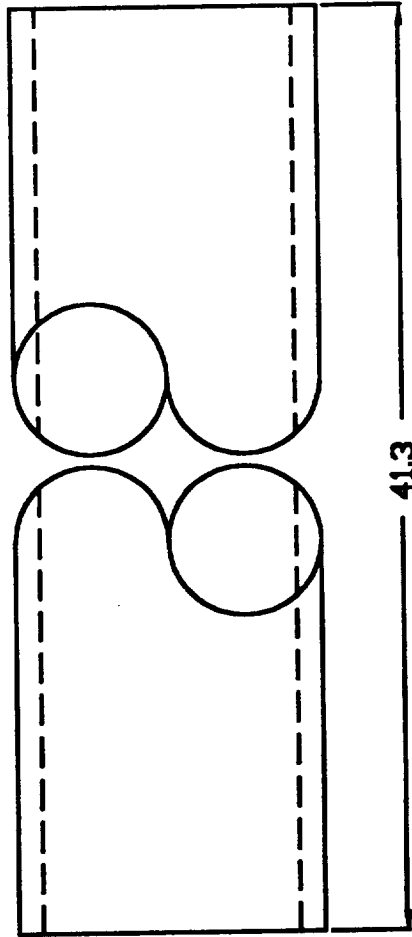
- NOTES:
- 1. SEE VIEWS FOR CLUTCH DIMENSIONS.
 - 2. CLUTCH TREAD.
 - 3. RUBBER FILLET ON ALL CORNERS.
 - 4. ALL DIMENSIONS ARE SYMMETRIC.



Position of exterior component of clutch. See End-flange dwg for details.

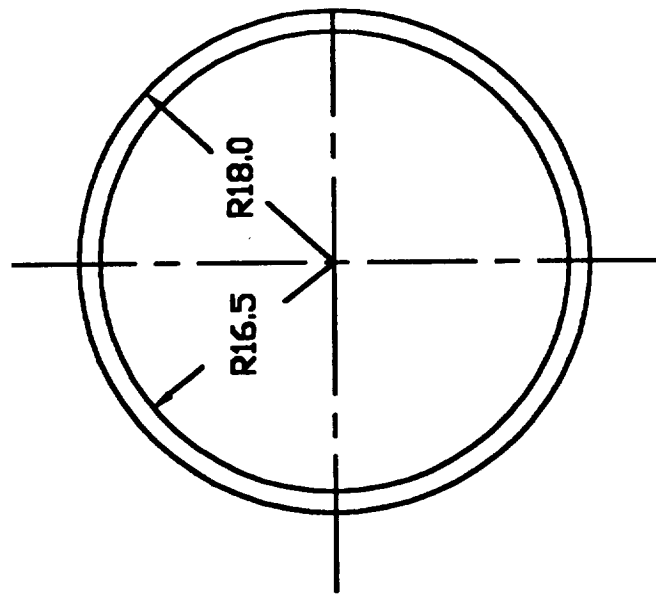
2 CROSS SECTION
WL.1
DIMENSIONED AS MARKED

Material: Wheel - Plastic Friction - Rubber		Wheel	
Tolerances: As to, +/- 0.05	General, +/- 0.5	E-DISH	ME 4182
Quantity Needed: 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLT	
		WH.1	
		SCALE: SEE DWG, 1/8"=1, mm	

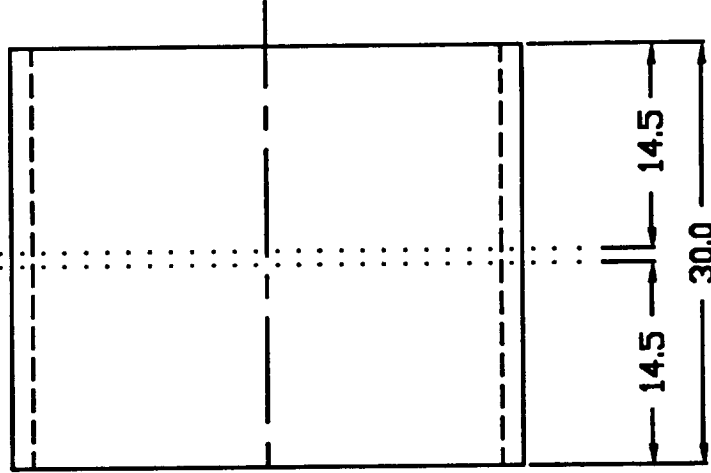


1 Secondary Wheel Axle
WL.2 DIMENSIONED AS MARKED

Materials Plastics		Secondary Axles	
Tolerances Inner Rad. ± 0.05 Outer Rad. ± 0.05		E-DISH	ME 4182
Quantity Made: 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	
		SCALE: SEE DWG, 1/8"=1, mm	
		WL.2	



LOCATION OF CENTRAL FLANGE.
SEE 1/CD2 FOR CENTER
FLANGE DIMENSIONS.

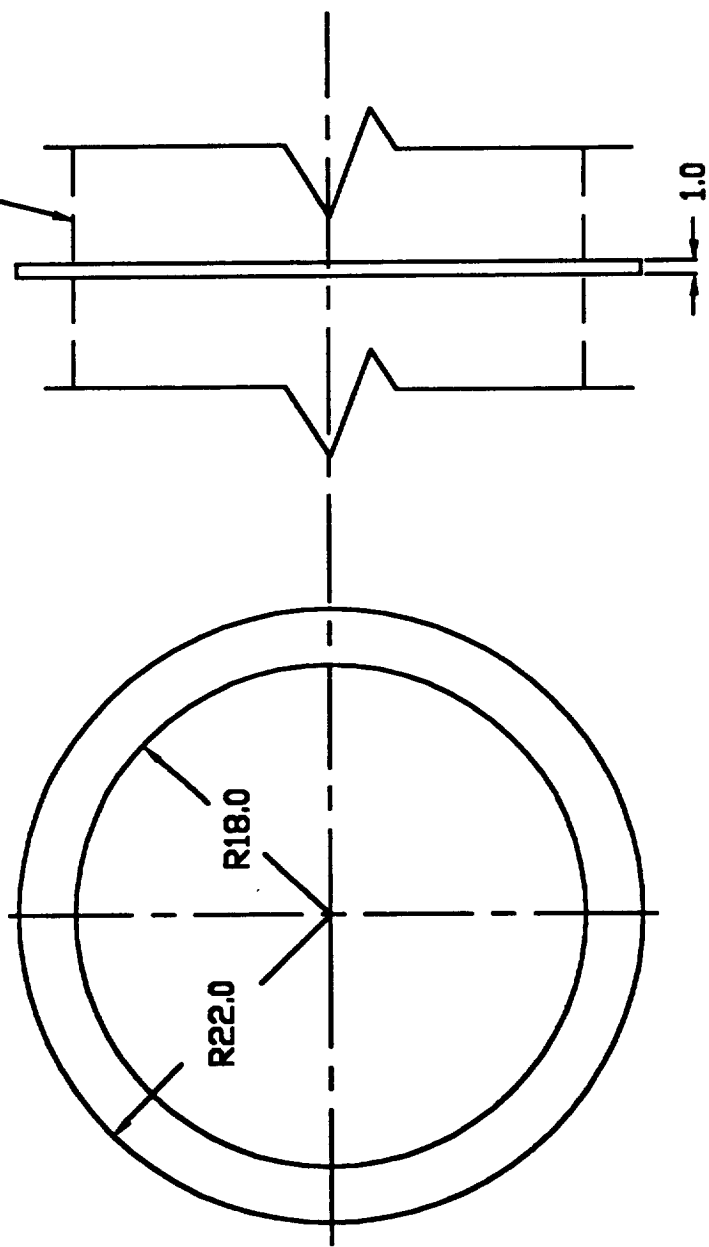


1 CABLE DRUM BODY
CD1 DIMENSIONED AS MARKED

Material: 6061 T6 Aluminum
Tolerances:
General, ± 1.0
Cut Rod, ± 0.05
Quantity Marked: 1

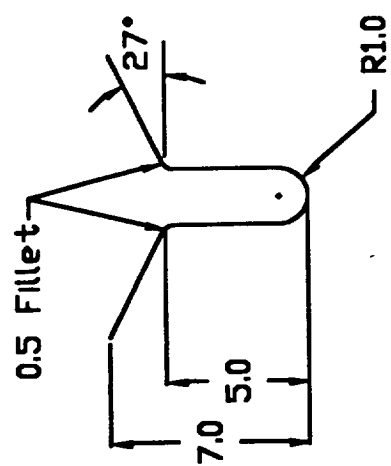
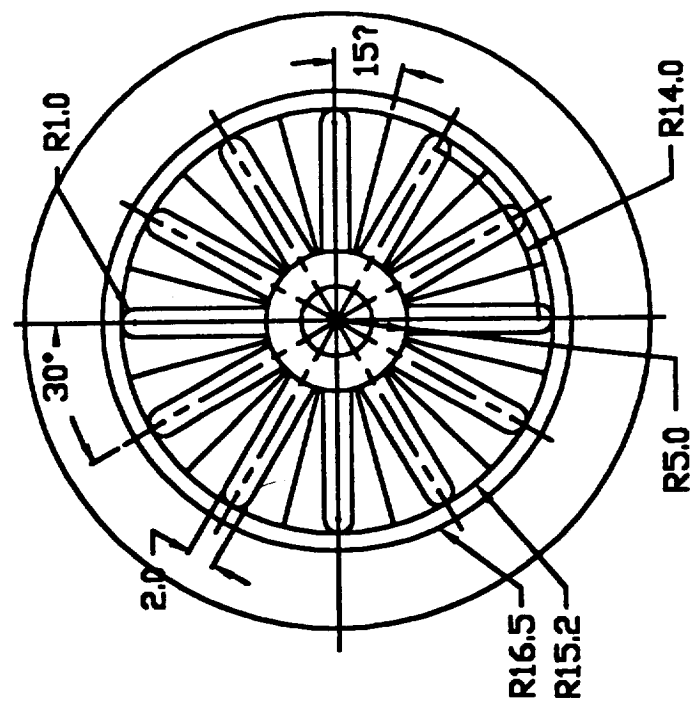
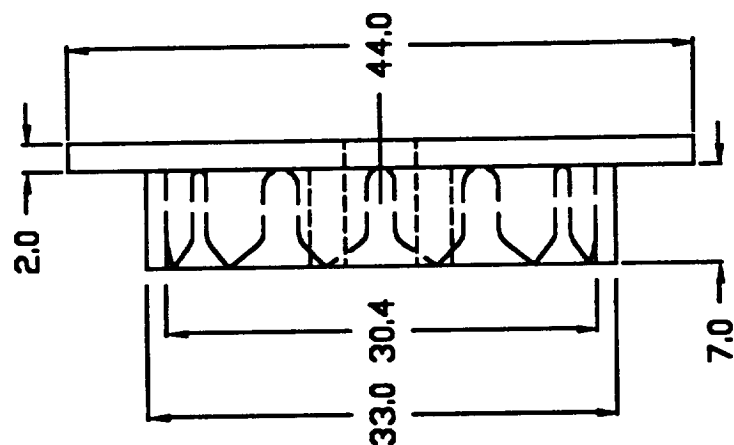
Cable Drum Body	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	CD.1
SCALE: SEE DWG, 1/2=1, mm	

EXISTING CABLE DRUM.
SEE 1/CD1 FOR DIMENSIONS.



1 CENTER DRUM FLANGE
CD2 DIMENSIONED AS MARKED

Materials Plastic	Center Drum Flange		
Tolerances Inner Rad. ± 0.08 Outside Rad. ± 0.10 Quantity Needed: 1	E-DISH	ME	4182
Georgia Institute of Technology			
DWN BY: GRAHAM HOLP			
SCALE: SEE DWG, 1/8"=1, mm			
CD.2			



2 Tooth Cut
CD.3
DIMENSIONED AS MARKED

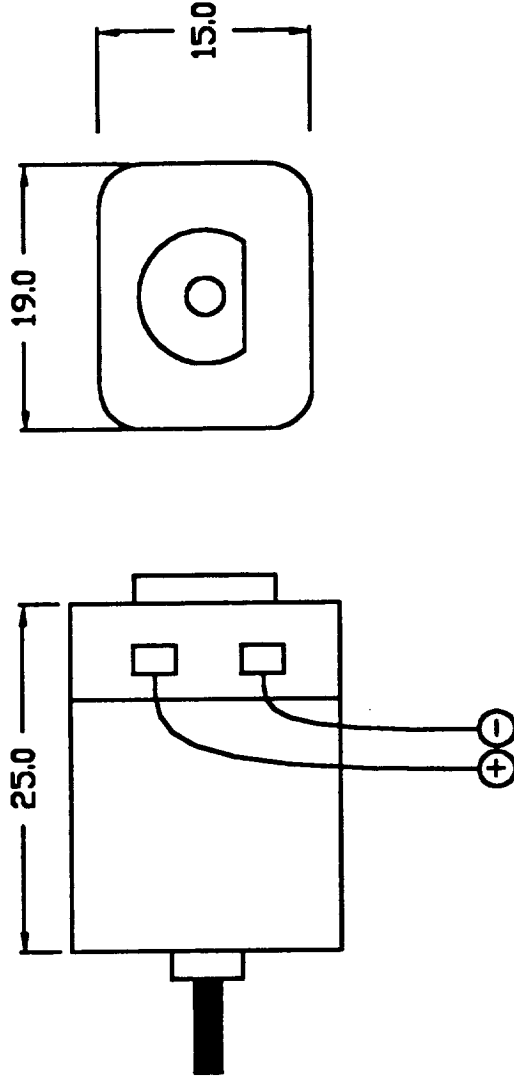
1 END FLANGE/OUTER CLUTCH
CD.3
DIMENSIONED AS MARKED

Note:
All dimensions are symmetric.

Material:
Pacfile
Tolerances:
Add. ± 0.05
Tooth Cut, ± 0.05
Quantity: 2

End Flange/ Outer Clutch	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	
SCALE: SEE DWG, 1/8"=1, mm	

CD.3

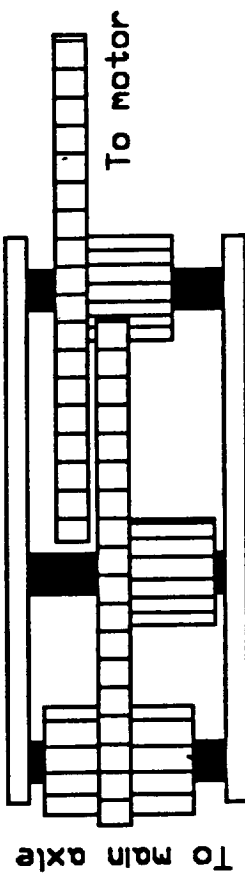
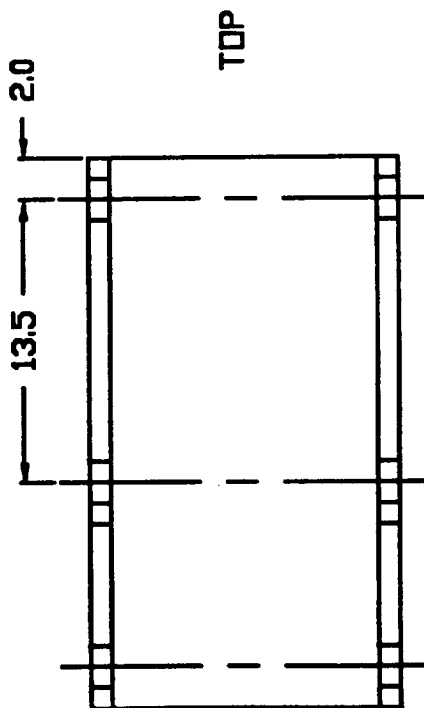
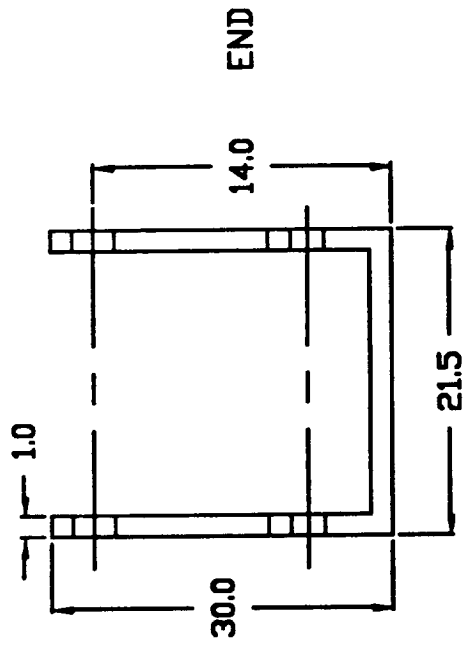
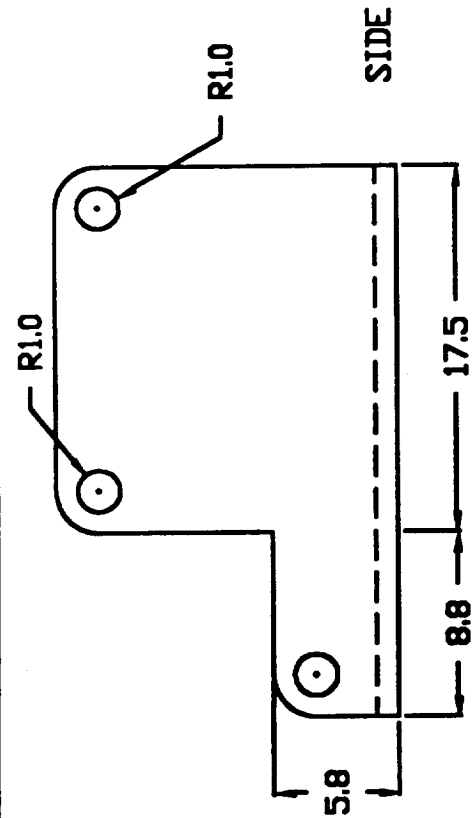


1 Electric Motors
PT.1
DIMENSIONED AS MARKED

NOTES:

1. Motors are Tamiya Model reversible electric motors. Motors are fixed 1000 rpm motors that are connected to "C" size batteries.
2. Three C30 motors are required for prototype manufacture.

Quantity Needed:		Electric Motor	
3		E-DISH	ME 4182
		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	PT.1
		SCALE: SEE DWG, 1/8"=1, mm	



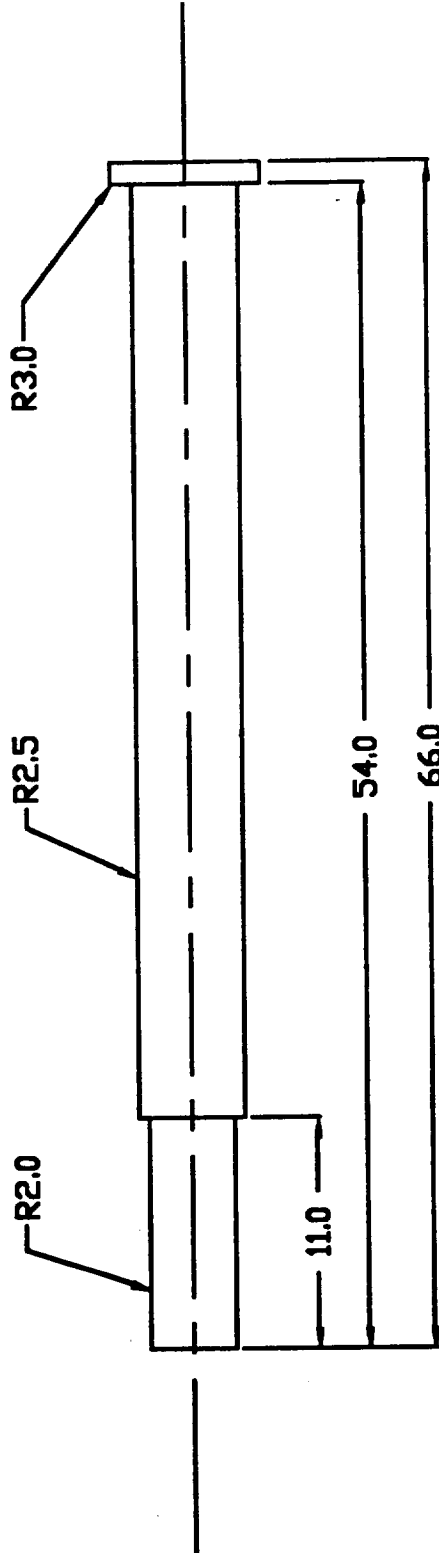
Schematic gear layout. See GI.1 for gear and shaft call numbers.

1 Gear Mounts
PT.2 DIMENSIONED AS MARKED

Note:

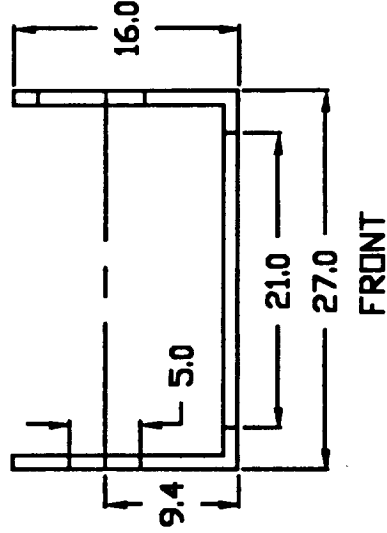
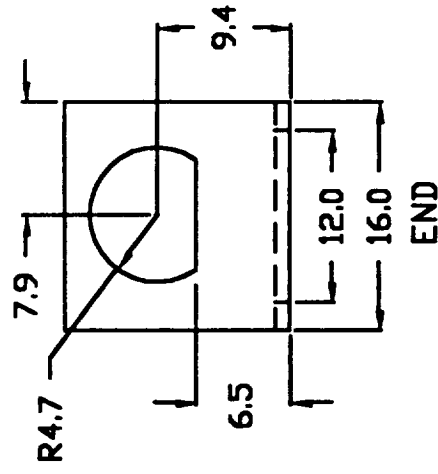
1. All hole centers are located on quadrant intercepts with the material edge.

Material: 6061 T6 Aluminum		Gear Mounts	
Tolerances: Center Line, +0.08 General, +0/-0.5		E-DISH	ME 4182
Quantity: 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	PT.2
		SCALE: SEE DWG, 1/8"=1, mm	

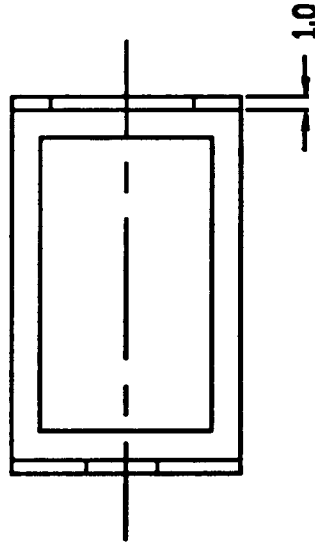


1 Main Axle
PT.3 DIMENSIONED AS MARKED

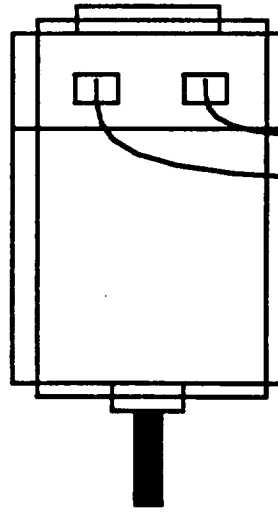
Materials Profile		Main Axle	
Tolerances Rad. ± 0.05 Lengths ± 0.5		E-DISH	ME 4182
Quantity 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	
		SCALE: SEE DWD, 1/8"=1. mm	
		PT.3	



TOP

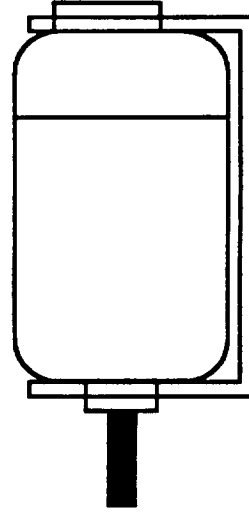


1 Motor Mount
PT.1 DIMENSIONED AS MARKED

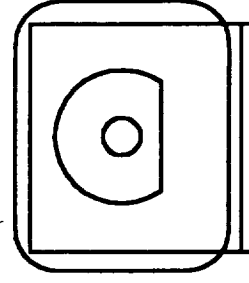


TOP

2 Motor Placed in Mount
PT.1 DIMENSIONED AS MARKED



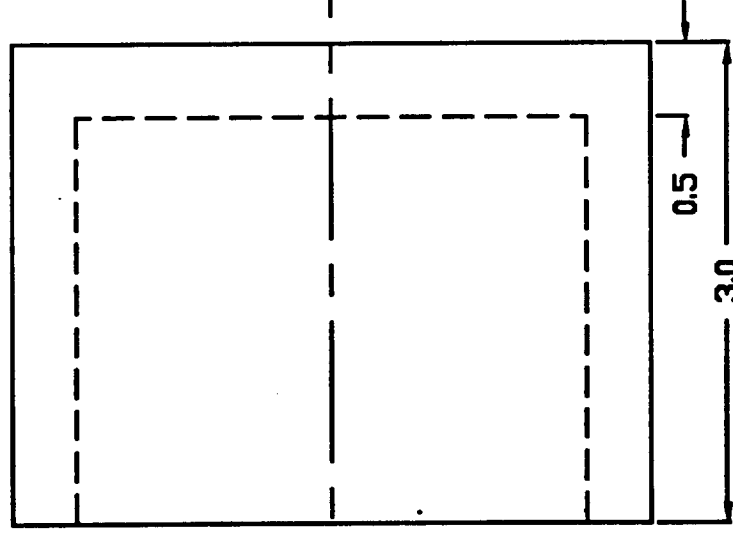
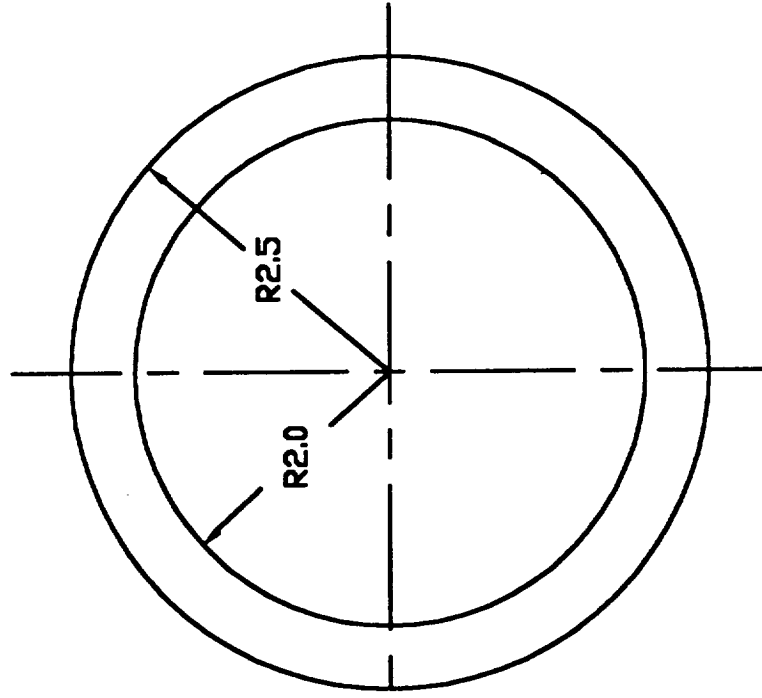
FRONT



END

Motor Mounts		E-DISH ME 4182	
Georgia Institute of Technology		DWN BY: GRAHAM HOLT	
Material: 6061 T6 Aluminum		SCALE: SEE DWG, 1/8"=1, mm	
Tolerances: Body Lengths, ± 0.5 Center Line, ± 0.5		PT.4	
Quantity Needed: 3			

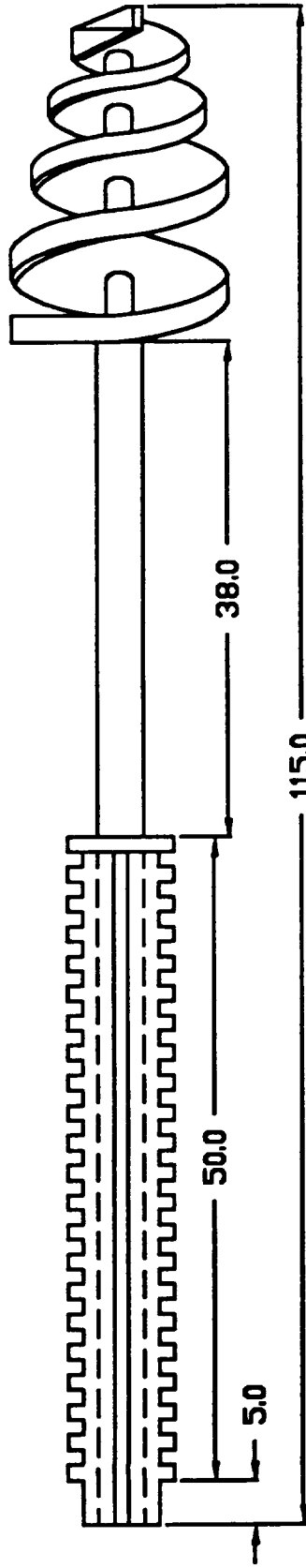
NOTES: 1. Mount is 3/8" thick. One piece of metal bent into shape.



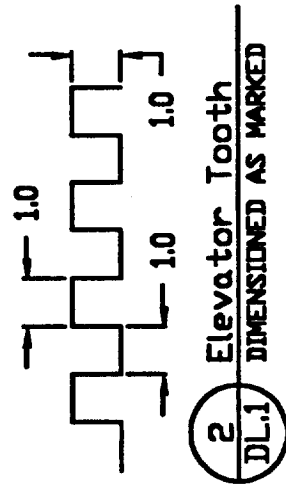
1 Main Axle Caps
PT.5
DIMENSIONED AS MARKED

Main Axle Caps	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	PT.5
SCALE: SEE DWG, 1/8=1, mm	

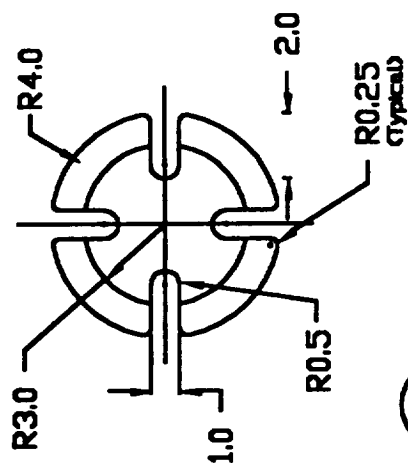
Materials
Plastics
Tolerances
Inner Rad. ± 0.06
Lengths ± 0.5
Quantity Needed:
2



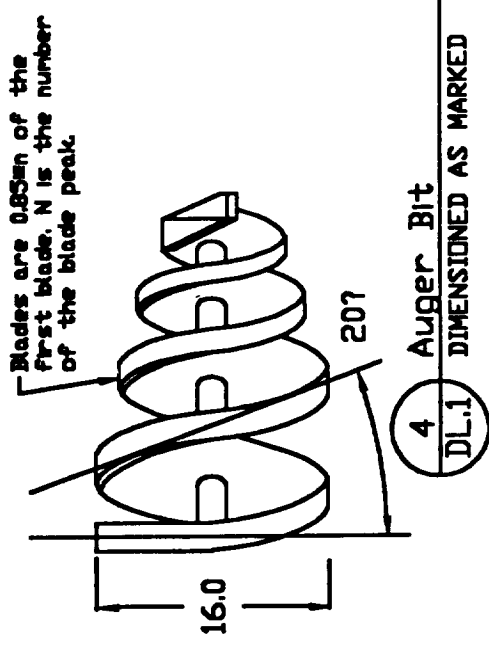
1 Auger Device
DL.1 DIMENSIONED AS MARKED



2 Elevator Tooth
DL.1 DIMENSIONED AS MARKED

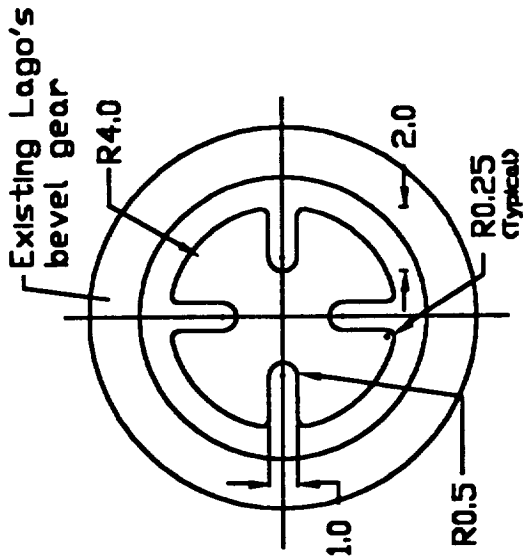


3 Elevator Section
DL.1 DIMENSIONED AS MARKED



4 Auger Bit
DL.1 DIMENSIONED AS MARKED

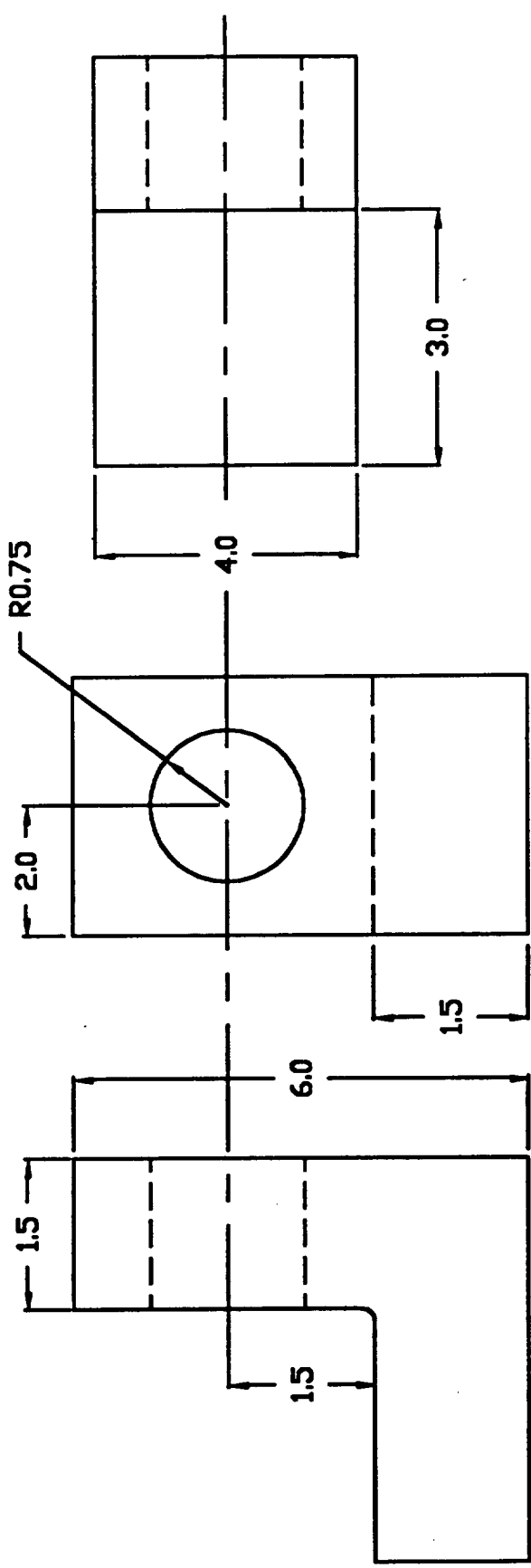
Material: 6061 T6 Aluminum		Auger Device	
Tolerances: Elevator Tooth, -0.5 Auger Bit, +/-1.0		E-DISH ME 4182	
Quantity: 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	
		DL.1	
		SCALE: SEE DWD, 1/8"=1, mm	



1 Auger Gear
DL.2 DIMENSIONED AS MARKED

Markings: Profile Tolerances Inner dia., +/-0.05 Quantity Needed: 2	Auger Gear		
	E-DISH	ME 4182	DL.2
	Georgia Institute of Technology		
	DWN BY: GRAHAM HOLP		
	SCALE: SEE DWG. 1/8=1, mm		

Material:
Plastic
Tolerances:
Inner cuts, ± 0.05
Quantity Needed:
2



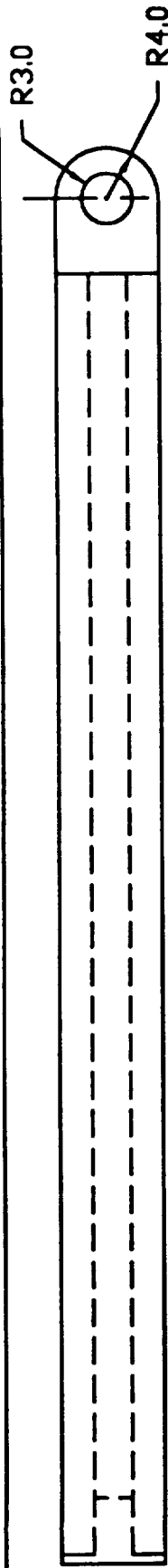
1 Drill Bracket- Side
SP.1 DIMENSIONED AS MARKED

2 Drill Bracket- End
SP.1 DIMENSIONED AS MARKED

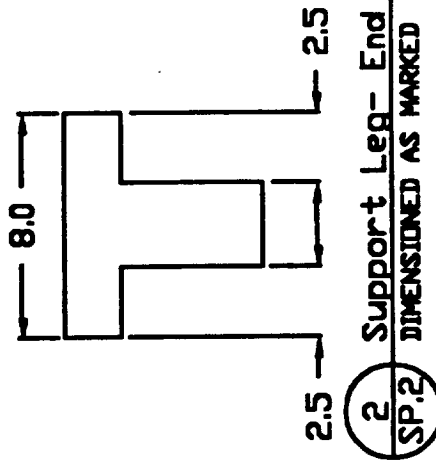
3 Drill Bracket- Top
SP.1 DIMENSIONED AS MARKED

Drill Bracket	
E-DISH	ME 4182
Georgia Institute of Technology	
DWN BY: GRAHAM HOLP	SP.1
SCALE: SEE DWG, 1/8"=1, mm	

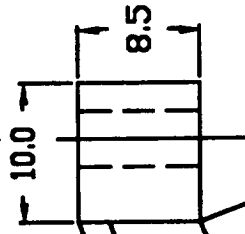
Materials 6061 T6 Aluminum	Tolerances Center Line, ± 0.5 General, ± 1.0	Quantity Needed 4
-------------------------------	--	----------------------



1 Support Leg- Top
SP.2 DIMENSIONED AS MARKED



2 Support Leg- End
SP.2 DIMENSIONED AS MARKED



3 Support Leg- Side
SP.2 DIMENSIONED AS MARKED

103.0

Material: 6061 T6 Aluminum
Tolerances:
General, ± 1.0
Critical, ± 0.5
Quantity Needed:
2

Support Legs

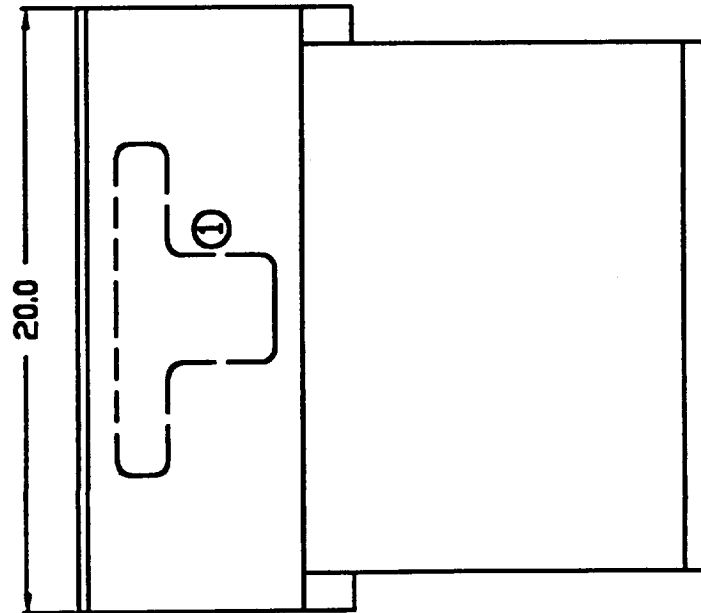
E-DISH ME 4182

Georgia Institute of Technology

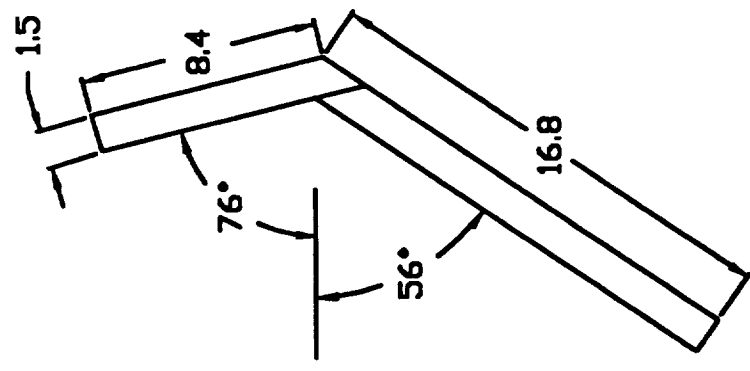
DWN BY: GRAHAM HOLP

SCALE: SEE DWG, 1/8"=1, mm

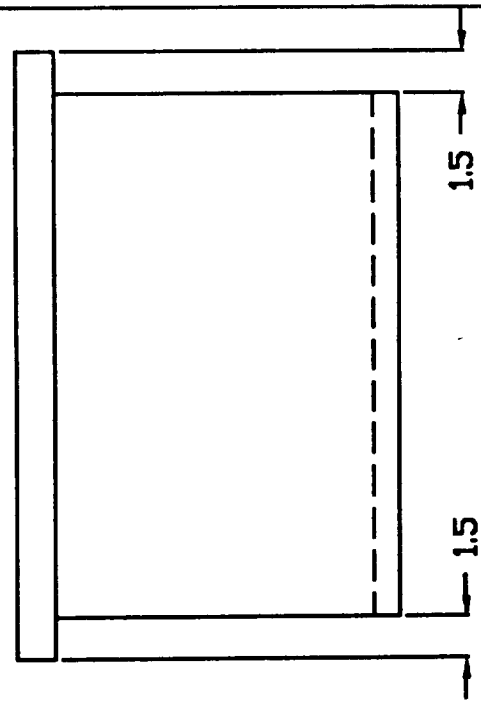
SP.2



1 SUP. BLADE- BACK
SP.3 DIMENSIONED AS MARKED

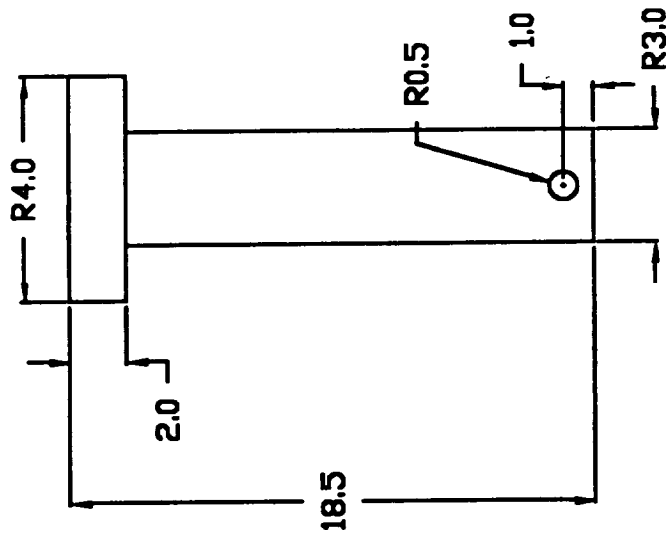


2 SUP. BLADE- SIDE
SP.3 DIMENSIONED AS MARKED



3 SUP. BLADE- TOP
SP.3 DIMENSIONED AS MARKED

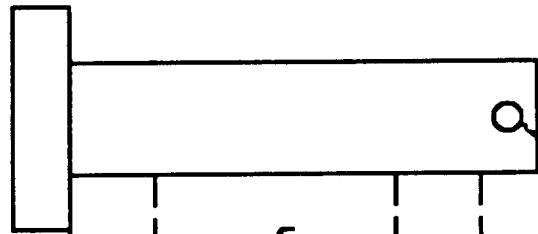
Material: 6061 T6 Aluminum		SUPPORT BLADES	
Tolerances: General, +/- 0.25		E-DISH	ME 4182
Georgia Institute of Technology		DWN BY: GRAHAM HOLP	
NOTES: 1. PLACEMENT OF BLADE TO BE VELDED TO SUPPORT LEG.		SP.3	
SCALE: SEE DWG, 1/8"=1, mm			



Support Pin

1
SP.4

DIMENSIONED AS MARKED



Cleavis Pin Hole

Body Frame

Support Leg Connection

Body Frame

Material:
Plastic

Tolerance:
Pin Shaft, -0.3
Pin Head, $+/- 1.0$
Quantity: 2

Support Pin

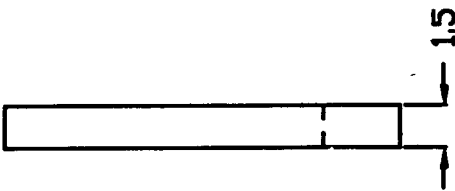
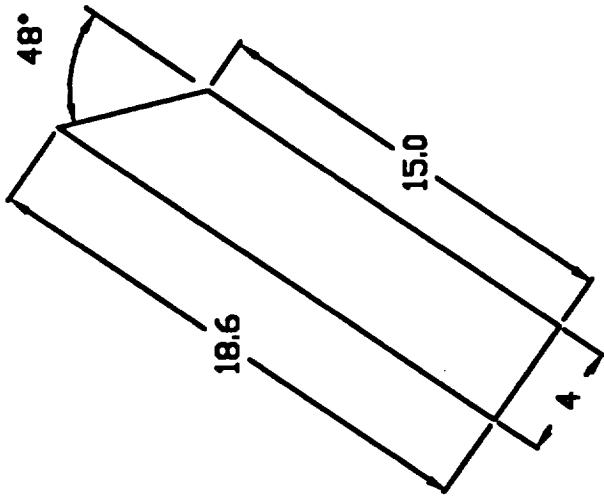
E-DISH ME 4182

Georgia Institute of Technology

DWN BY: GRAHAM HOLP

SCALE: SEE DWG, 1/8=1, mm

SP.4

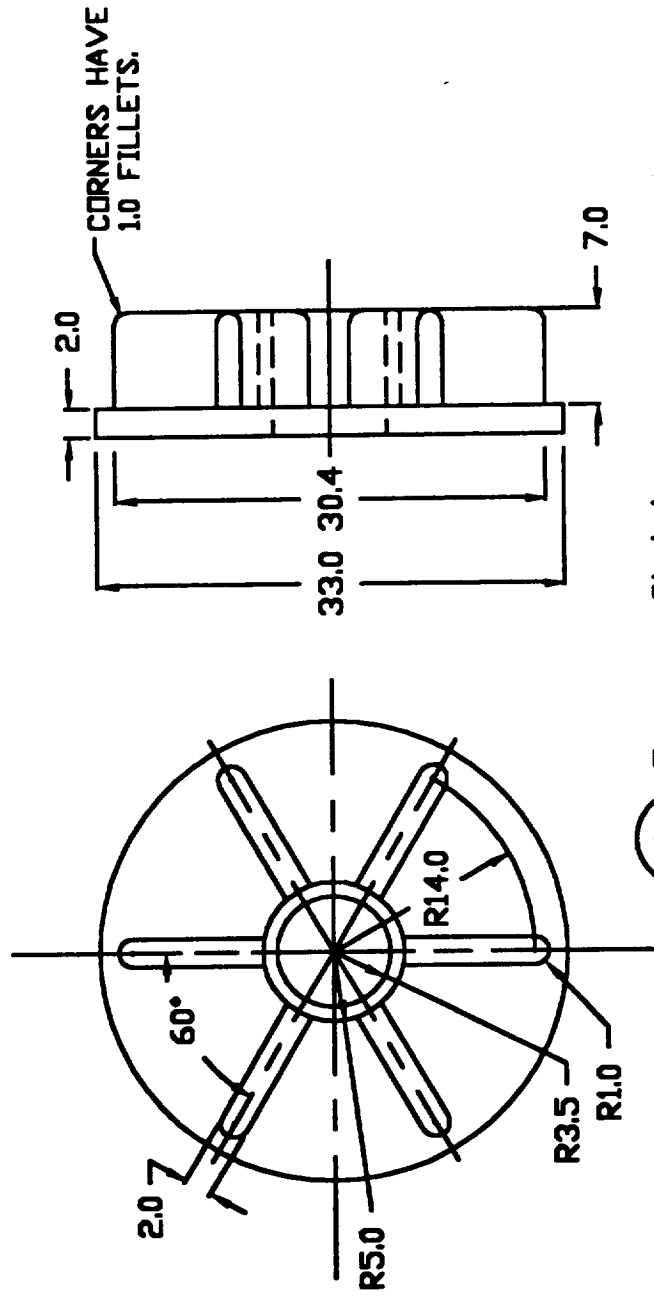


3 Blade Caps- Top
SP.5 DIMENSIONED AS MARKED

2 Blade Caps- Side
SP.5 DIMENSIONED AS MARKED

1 Blade Caps- Back
SP.5 DIMENSIONED AS MARKED

Material: 6061 T6 Aluminum		Blade Caps	
Tolerances: General, +/- 0.5		E-DISH	ME 4182
Quantity: 2		Georgia Institute of Technology	
		DWN BY: GRAHAM HOLP	SP.5
		SCALE: SEE DWG, 1/8"=1, mm	



1 Engaging Clutch
CL.1 DIMENSIONED AS MARKED

NOTES:

1. See 2/CL.3 for rated clutch component.

Materials:
Plastic

Tolerances:
As to, +0.05
Clutch Springs, -0.05
Quantity: 2

Engaging Clutch

E-DISH ME 4182

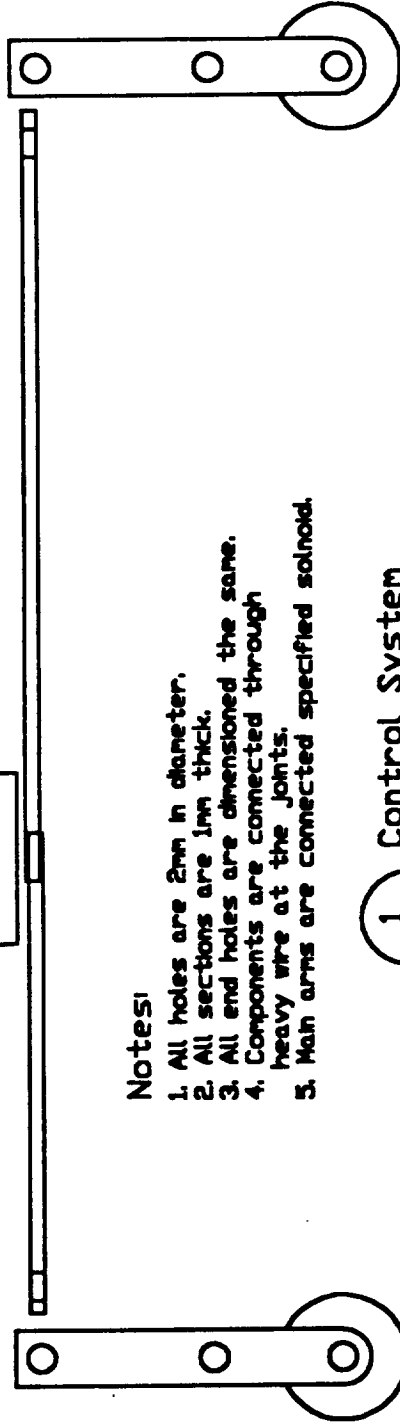
Georgia Institute of Technology

DWN BY: GRAHAM HOLP

SCALE: SEE DWG, 1/2=1, mm

CL.1

Specified Solnoid

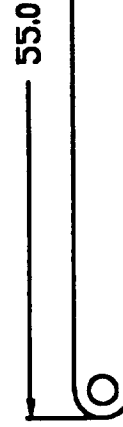
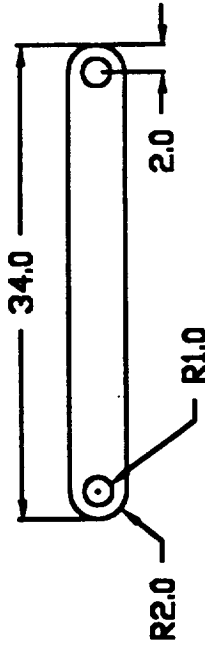


Notes:

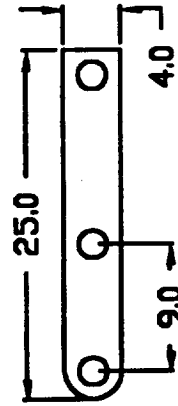
1. All holes are 2mm in diameter.
2. All sections are 1mm thick.
3. All end holes are dimensioned the same.
4. Components are connected through heavy wire at the joints.
5. Main arms are connected specified solnoid.

1 Control System
CS.1 DIMENSIONED AS MARKED

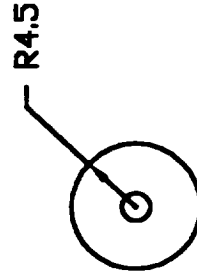
Quantity needed (1)



Quantity needed (1)



Quantity needed (2)



Quantity needed (2)

Material:
Plastic

Tolerances:
General: +/-1.0

Quantity Needed:
As noted

Control System

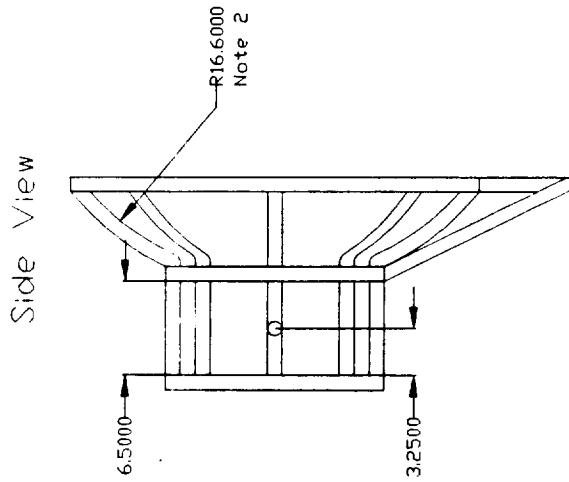
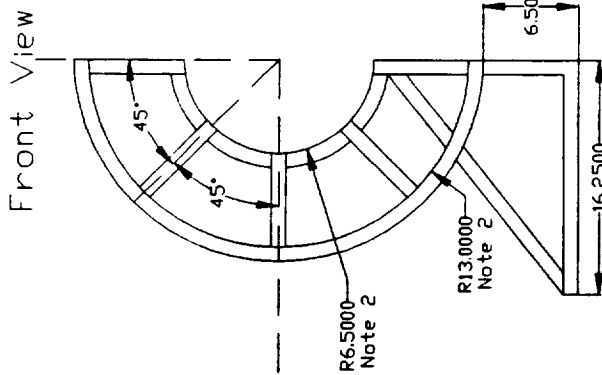
E-DISH ME 4182

Georgia Institute of Technology

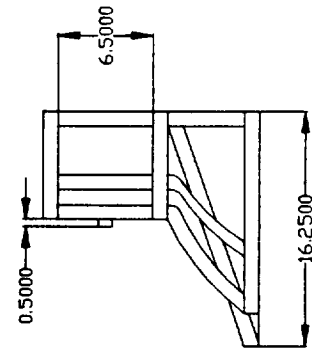
DWN BY: GRAHAM HOLP

SCALE: SEE DWG, 1/8"=1, mm

CS.1



Top view

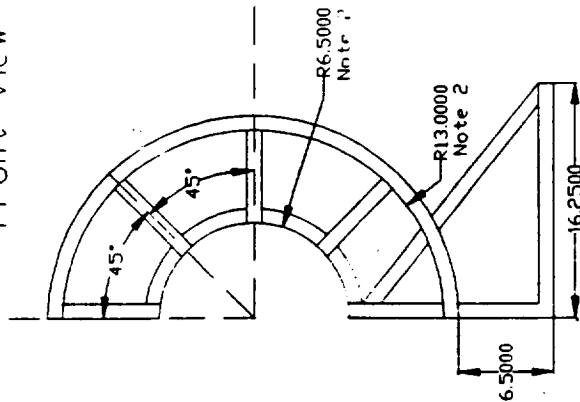


1 Left Cone Note 1
C.1 DIMENSIONED AS MARKED

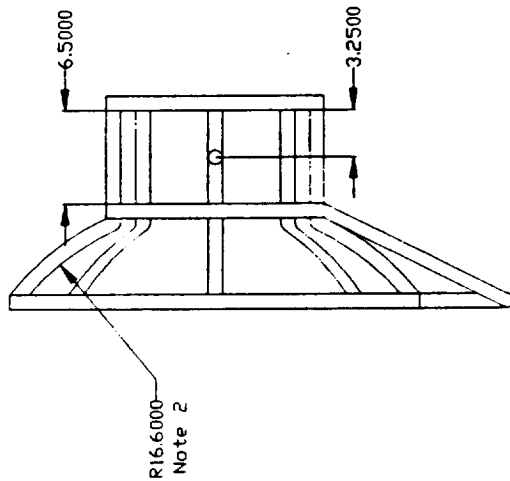
Material
Carbon Steel Wire
Wire Diameter - 4mm
Note:
1. All joints welded
2. Radius of Curvature

Left Cone	
E-DISH	HE 4182
Georgia Institute of Technology	
DWN BY: SIAO LY	C.1
SCALE: SEE DWG, 1/8=4mm	

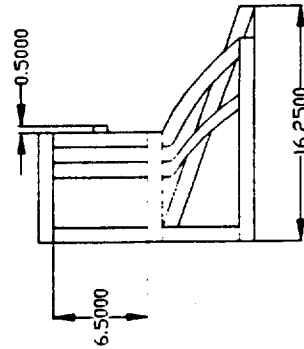
Front View



Side View



Top view



2 Right Cone Note 1
C.2 DIMENSIONED AS MARKED

Material
Carbon Steel Wire
Wire Diameter - 4mm
Note:
1. All joints welded
2. Radius of Curvature

Right Cone

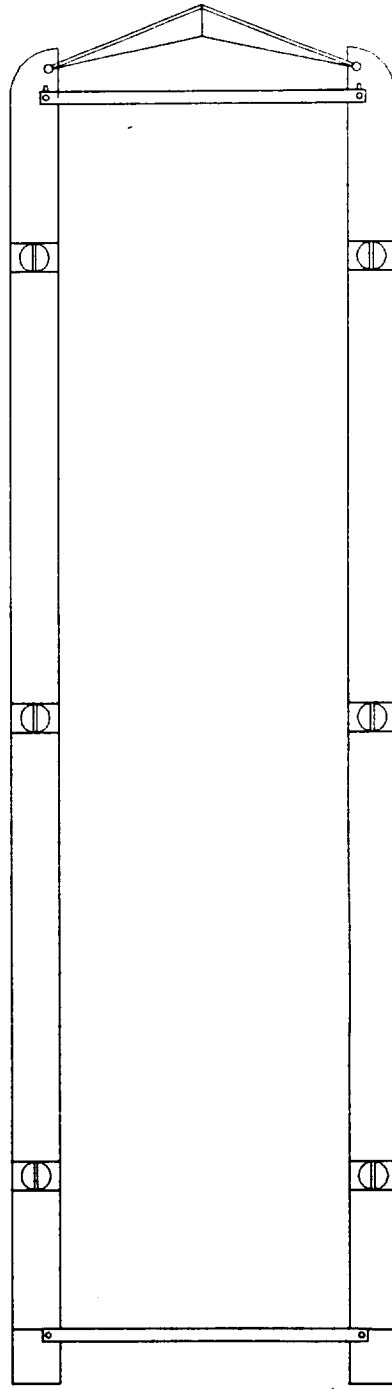
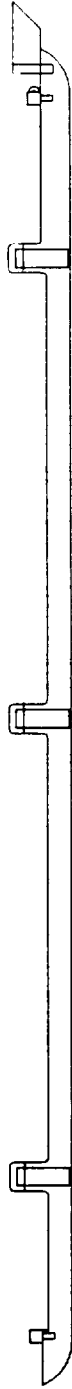
E-DISH HE 4182

Georgia Institute of Technology

DWN BY: SIAO LY

SCALE: SEE DWG, 1/8=4mm

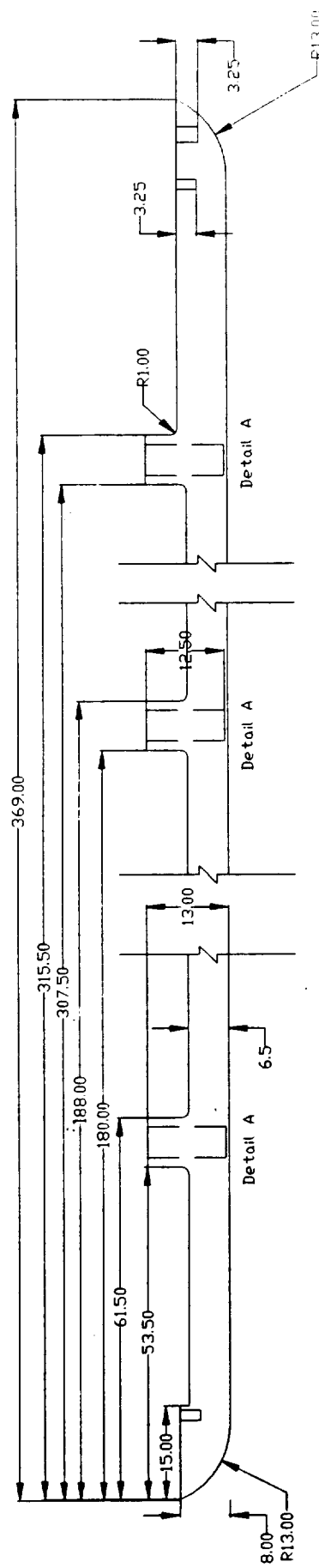
C.2



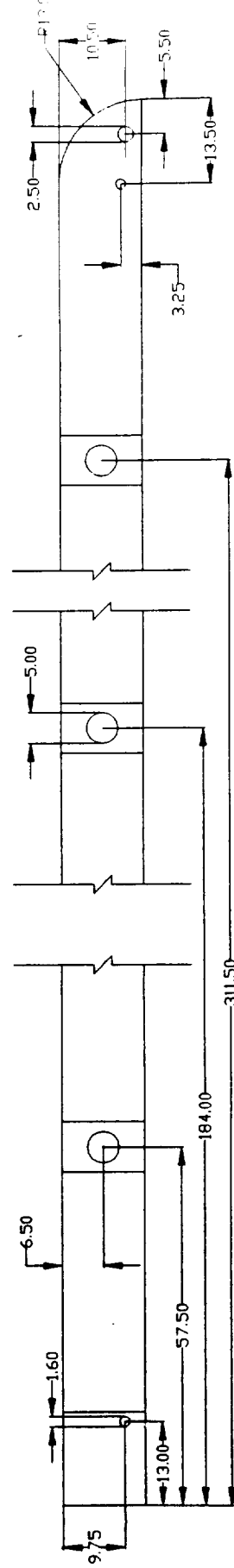
Material:
6061 Aluminum
Tolerances:
Axle -
Gear teeth -

Skid Assembl.
E-DISH IE 4182
Georgia Institute of Technology
DWN BY: STADLY
S1

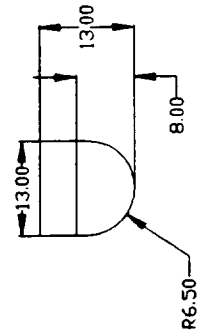
Side View



Top View



Front View



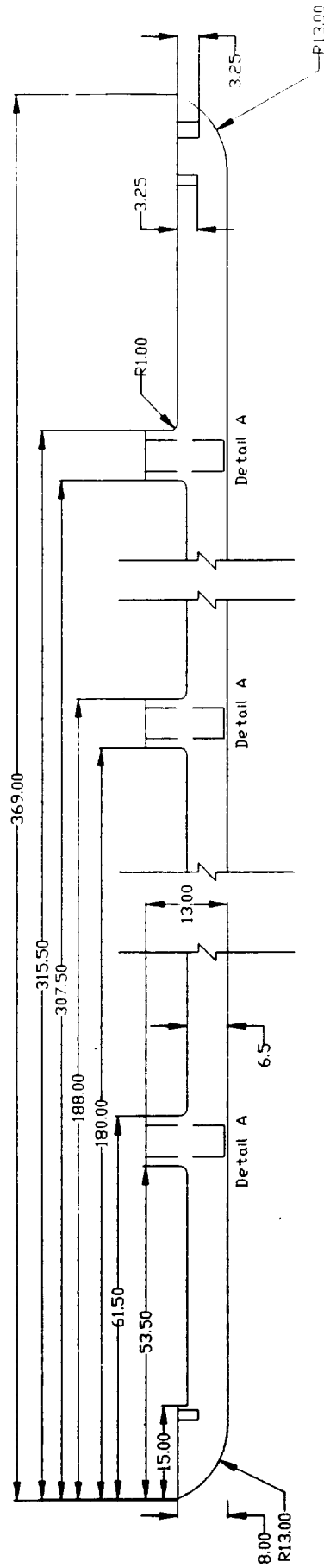
1 Right Skid Ski
S2.1 DIMENSIONED AS MARKED

Material: 6061 Aluminum
Tolerances:
Axle -
Gear teeth -

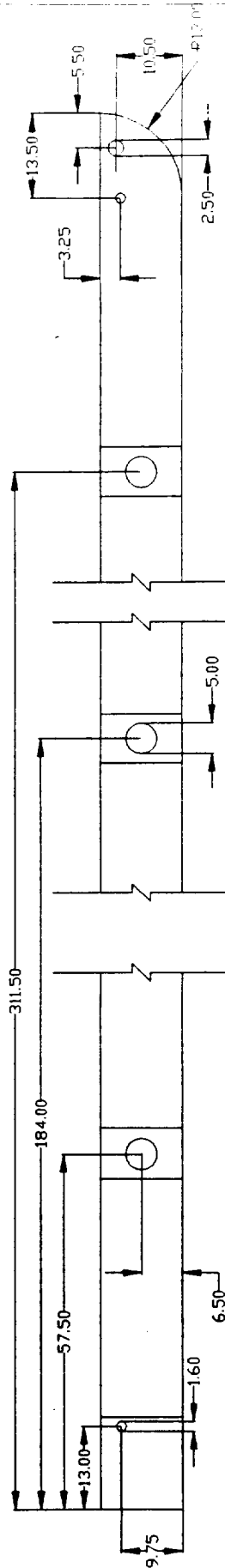
Right Skid Ski		
E-DISH	ME	4182
Georgia Institute of Technology,		
DWN BY:	SIAD LY	
SCALE: SEE DWG. 1/8=1, mm		

S2.1

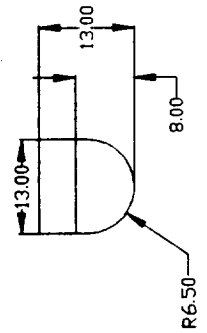
Side View



Top View



Front View



1 Left Skid Ski
S2.2 DIMENSIONED AS MARKED

Material:
6061 Aluminum
Tolerances:
Axle -
Gear teeth -

Left Skid Ski

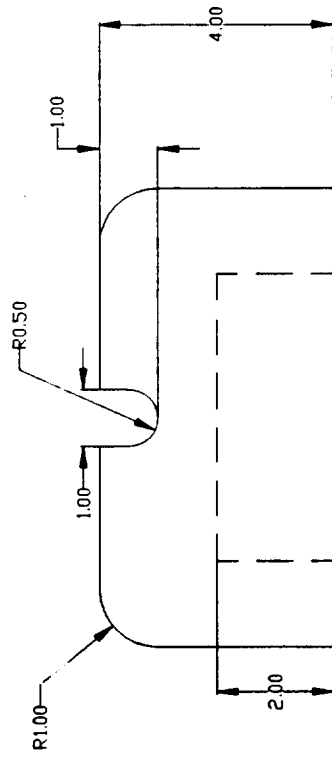
E-DISH IE 4182

Georgia Institute of Technology

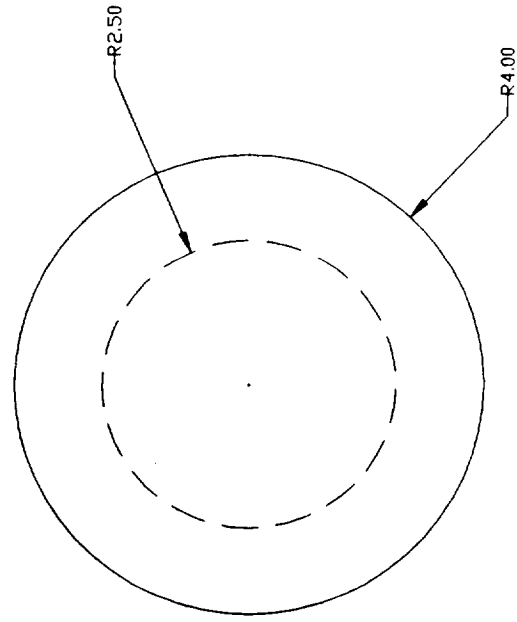
DWN BY: SHD L1

SCALE: SEE DWG. 1/8"=1, mm

S2.2



Side View



Top View

1 Power Screw Head
S2.3 DIMENSIONED AS MARKED

Material: 6061 T6 Aluminum
Tolerances:
Axle -
Gear teeth -

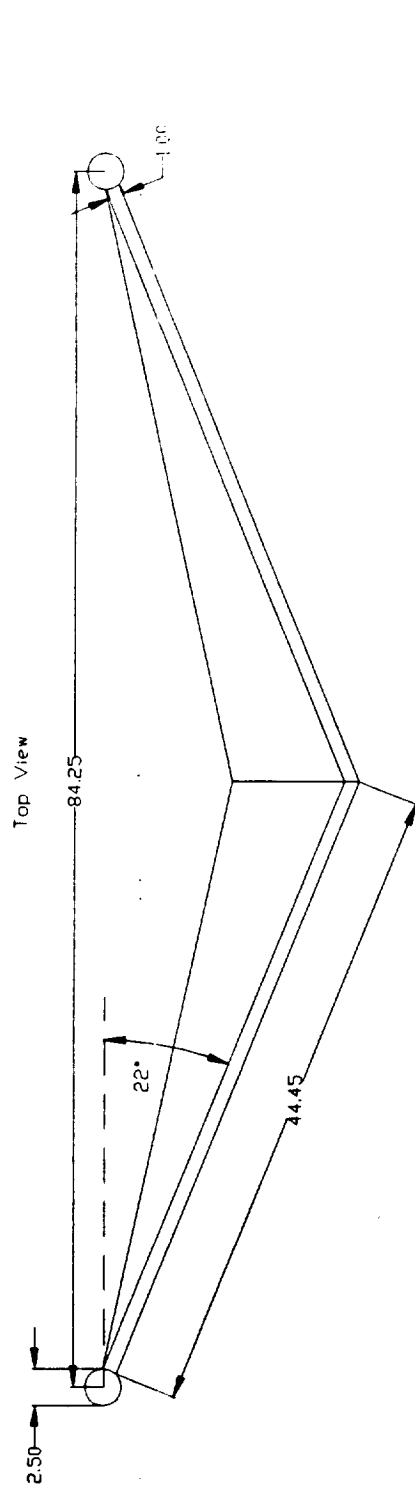
Power Screw Head
E-DISH IRE 4182

Georgia Institute of Technology

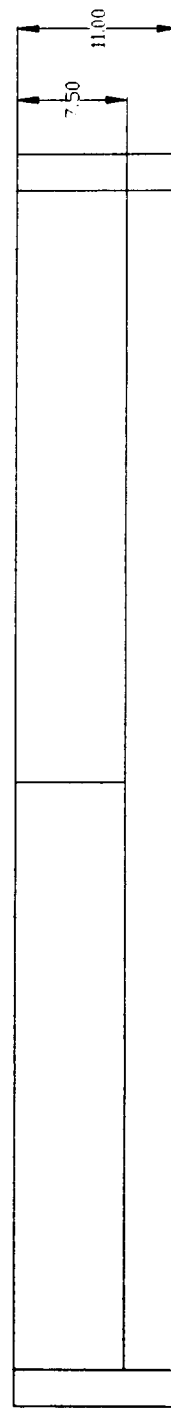
DWJ BY: SIAD LY

SCALE: SEE DWG, 1/8"=1" mm

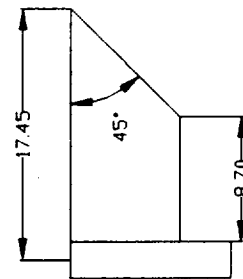
S2.3



Front View



Side View



1 Skid Door
S3 DIMENSIONED AS MARKED

Material:
6061 Aluminum
Tolerances:
Axle -
Gear teeth -

Skid Shield

E-DISH HE 4182

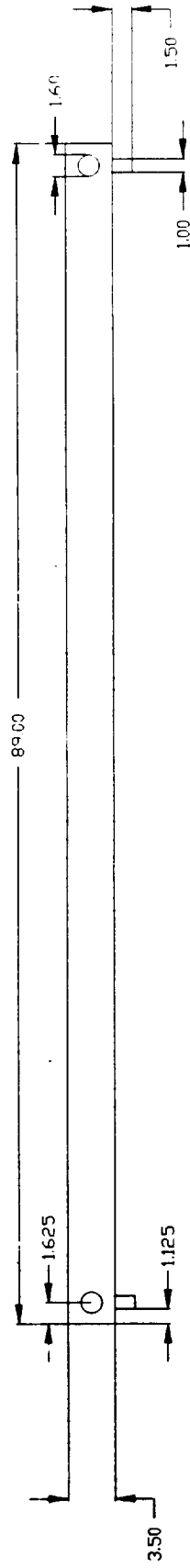
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DWG BY: SHD LY

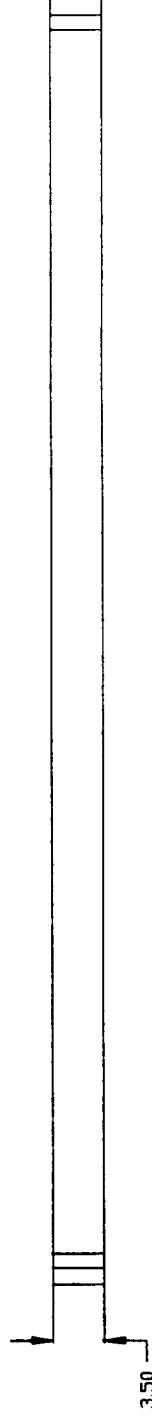
SCALE: SEE DWG, 1/8"=1" mm

S3

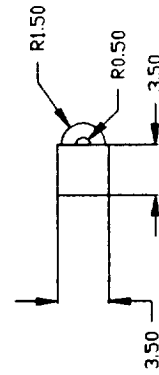
Top View



Side View



End View



1 Front Crossbar
S4
DIMENSIONED AS MARKED

Material: 6061 Aluminum
Tolerances:
Axle -
Gear teeth -

Front Crossbar
E-DISH HE 418

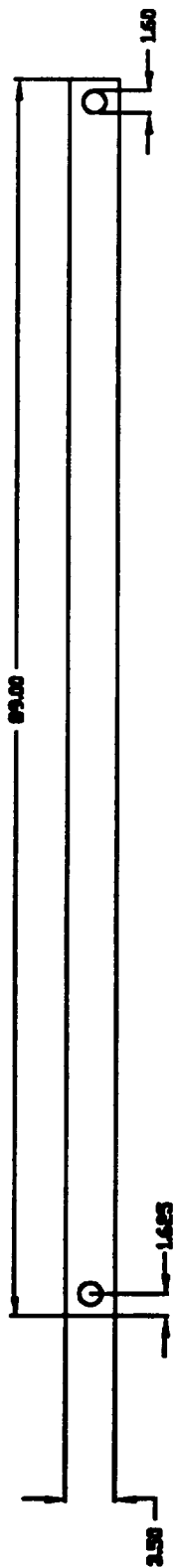
Georgia Institute of Technology

DWII BY: SHD LY

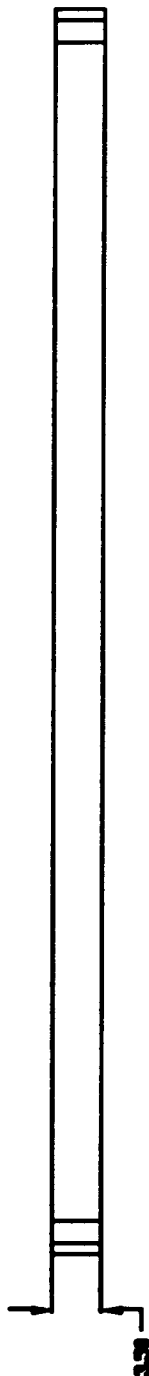
SCALE: SEE DWG. 1/8=1, mm

S4

Top View



Side View



1 Back Crossbar
S5 DIMENSIONED AS MARKED

Material:
6061 T6 Alum
Tolerances
Fillet -
Gear teeth -

Back Crossbar

E-DISH ME 4182

Georgia Institute of Technology

DEVN BY: SIAD LY

SCALE: SEE DWG 1/8"=1, IN

S5

Assembly Instructions

Assembly Procedure for E-DISH's increment prototype

General

1. Verify all dimensions and clearances and amend construction documents as needed.
2. Read all assembly procedures before construction of the components or final assembly.
3. Manufacture all components out of specified material.

Wheels

- a. Adhere the outside rubber traction tread to the wheel rim. Align tread so no over-lap is present.

Cable Drum

- a. Obtain the Cable Drum Body, Center Drum Flange, and End Flanges.
- b. Position the Center Drum Flange on the Cable Drum Body such that there are equal distances between the center point of Center Drum Flange and the edges of Cable Drum Body.
- c. Solder into position.
- d. Position the right End Flange onto the Cable Drum Body such that the center lines of the two components match. Center the Flange onto the Drum Body. Solder into place.
- e. Place Right Main Axle through the End Flange axle hole such that the smallest diameter of the shaft is pointing outward to connect to the wheel.
- f. Place Left Main Axle through left End Flange in the same manner.
- g. Repeat step (d) for left side End Flange.
- h. The completed Cable Drum System should have the cable drum enclosed with the main axles poking out of the drum body, free to turn and to attach to the wheel system.

Secondary Axle

- a. Obtain gear (K), secondary axle, two (2) engaging clutch components, and body frame.
- b. On the right front of the frame, locate the "U" axle holes. Slide the secondary axle through one of the axle holes.
- c. Slide gear (K) over the secondary axle and slide axle such that it passes through both "U" axle holders.
- d. Position gear (K), 19mm from outside edge of secondary axle. Solder into position.
- e. Attach the external clutch components to be ends of the secondary axle. Solder into position.
- f. Repeat for left side.

Drum and Wheel connection to frame

- a. Obtain Frame, Cable Drum, and Wheel components.
- b. Slide the main axle through the secondary axle such that the end of the main axle is clear of clutch components.
- c. Repeat for opposite side.
- d. Cable Drum should now be attached to the body frame through the main axle running through the secondary axles. Both axles should be free to turn.
- e. Slide wheels over the outside section of the main axle such that the wheel hub is flush with main axle transition.
- f. Attach Axle Caps over the end of the main axle to secure wheel. Use an adhesive for connection.
- g. Repeat for opposite side.

Motors

- a. Obtain two (2) Motors, two (2) Gear (D), and two (2) motor mounts.
- b. Place Motors with-in the motormounts.
- c. Slide Gear (D) over motor shaft and secure with adhesive.
- d. Repeat process.

Geartrain

- a. Obtain gearmounts, shafts (A, B, and C), and gears (A,B, and C).
- b. Using drawing GI.1 and schematic gear layout on drawing PT.2, position gears and shafts with in gear mount. Slide the shaft through left side of gearmount, slide the gear over the shaft and push the shaft out the right side of the gearmount. Adhere the gear to the shaft to secure shaft with-in the gearmount. All gears are to be engaged with one another and allowed to rotate freely.

Powertrain connection

- a. Obtain body frame, gearmounts, and mounted motors.
- b. On right side of body frame, slide secondary axle all the way to the left. Adhere gear mount such that gear (A) is engaged with gear (K) on the far left side. The proper placement and action of the secondary axle should be checked before adhesion takes place. To do this, slide gear (K) to the far right side. At this position, gear (K) should still be engaged with gear (A).
- c. Mirror process for left side gear mount.
- d. After the gearmounts are secured in place. Position motors such that gear (D) is engaged with gear (C). Secure motormounts with adhesive.

Support Systems

Drill motor

- a. Follow same mounting procedure as with normal motor mounts but replace gear (D) with gear (H).
- b. Position gear (F) in rear side small hole. Secure with 2mm microscrew. Assure that gear (F) is free to rotate without interference.
- c. Slide rubber V-belt over gear (F) and place near, centerline of frame.
- d. Secure gear (J) to center line of body frame, through V-belt. Position gear (J) such that it is engaged with gear (H). Secure with 2mm microscrew.
- e. Repeat for other side of frame.
- f. Support device to this stage should spin both V-belts to gears (F).
- g. Position gear (E) over frame drill support hole and engaged with gear (F).
- h. Slide auger into gear (E).
- i. Slide gear (I) over shaft (D) such that it is engaged with gear (H) when shaft is in proper position.
- j. Slide two (2) drill brackets onto each end of shaft. Total of four (4) brackets.
- k. Attach gears (G) to the shaft through adhesives.
- l. Adhere the bottom of the brackets in a manner that one is near the auger and one is near the main motor. Before adhesion is complete, align all gears so that gears (G) are engaged with auger and gear (H) is engaged with gear (I).
- m. Proper action should be that when the motor is engaged, gear (J) to gear (F) cause the auger to spin, and the connection, gear (I) to gear (G) cause the auger to raise or lower depending on motor rotation.

Support Legs

- a. Weld blade caps to each side of blade.
- b. Weld blade to end of support leg.
- c. Position support leg into body frame.
- d. Slide support pin through body frame and support leg.
- e. To secure the pin, use a clevice pin through the pin hole.
- f. Repeat process.

Cable.

- a. Take model cable and attach to endflange through the cable hole. Wrap the cable around the drum.

Clutch Controls

- a. Using CS.1 as the reference, connect the control levers as illustrated.
- b. Connect the right side control lever to the upper hole on the solenoid and the left hand control lever to the lower solenoid hole.
- c. Secure levers to solenoid by 2mm microscrews.
- d. Secure Solenoid to the bottom of the body frame using GI.1 as a reference.
- e. Connect the control levers to the frame by placing 2mm microscrews through the middle hole on the levers into the front side hole on the body frame.

Power

- a. Place battery holders on bottom of frame using GI.1 as a reference. Make sure batteries do not interfere with the proper operation of the device.
- b. Solder wires to motors and control pack and route to battery holders and control panel.

Assembly Procedure for E-Dish's Skid Prototype

General

1. Verify all dimensions and clearances and amend construction documents as needed.
2. Read all assembly procedures before construction of the components as necessary.
3. Manufacture all components from the specified material.

Skid

- a. Thread each of the six power screws into the holes on the skis.
- b. Attach one the floating heads to each of the power screws.
- c. Attach the rear cross-brace to the skis using two M1.6 x 0.35 coarse pitch screws.
- d. Attach the front cross brace to the skis using two M1.6 x 0.35 coarse pitch screws. Orient the brace so that the cable attachment rings face the front of the skid.
- e. Affix the gate to the front of the skid by sliding the pins into the holes on the front of the skis.

Assembly Procedure for E-DISH's Connection Prototype

General

1. Verify all dimensions and clearances and amend construction document as needed.
2. Read all assembly procedures before construction of the components or final assembly.
3. Manufacture all components out of specified material.

Cone

- a. Obtain the Left and Right Cones.
- b. Attach the Left and Right Cones onto the connection seal of the existing module.
- c. Get two orthodontic appliance rubber bands.
- d. Make sure the gap division between the left and right cones is vertical.
- e. Attach one rubber band to the side of the left cone, pull across the top and attach to the side of the right cone.
- f. Attach the other rubber band to the side of the right cone, pull across the bottom and attach the to the side of the left cone.

Calculation Appendix

**Flange Diameter Calculation
ME 4052 Cable Drum Design**

	Rope Type	Rope Weight (kg)	H Flange Diameter (m)	H Flange Diameter (ft)	A Rope space Depth (in)	d Rope Diameter (in)	D Drum Diameter (in)	B Width betw Flanges (in)	L Rope Length (ft)
One rope 200 m	6x7	696.47	1.09	3.59	2.52	1.25	33.75	47.25	656.17
	6x19	744.09	1.73	5.67	1.58	1.25	56.25	47.25	656.17
	6x37	720.28	1.04	3.42	2.52	1.25	33.75	47.25	656.17
	8x19	815.53	1.34	4.40	2.43	1.375	42.63	47.25	656.17
Two ropes 200 m	6x7	892.91	0.88	2.87	2.00	1	27.00	47.25	656.17
	6x19	732.19	1.17	3.85	1.11	0.875	39.38	47.25	656.17
	6x37	922.68	0.88	2.87	2.00	1	27.00	47.25	656.17
	8x19	863.15	0.97	3.20	1.77	1	31.00	47.25	656.17
One rope 100 m	6x7	348.24	1.10	3.60	2.58	1.25	33.75	23	328.08
	6x19	372.05	1.73	5.69	1.62	1.25	56.25	23	328.08
	6x37	360.14	1.04	3.43	2.58	1.25	33.75	23	328.08
	8x19	407.76	1.34	4.41	2.49	1.375	42.63	23	328.08
Two ropes 100 m	6x7	446.46	0.88	2.88	2.05	1	27.00	23	328.08
	6x19	366.09	1.18	3.86	1.14	0.875	39.38	23	328.08
	6x37	461.34	0.88	2.88	2.05	1	27.00	23	328.08
	8x19	431.57	0.98	3.21	1.82	1	31.00	23	328.08

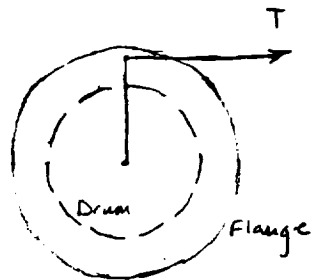
DRUM TORQUE for MOTOR REQUIREMENTS

Cable Tension = 152807 N

Drum Diameter = 1 m

Flange Diameter = 1.18 m

Rope Depth Space = 2.9 cm



Maximum Torque Radius = 0.529 m

Maximum Torque = $(152807 \text{ N})(0.529 \text{ m})$
 $= 80834.9 \text{ N-m} \approx 80.8 \text{ kN-m}$

* Need per unit time for Watts $\rightarrow$ hp.

Revolution Time		Power Requirement	
RPM	RAD/SEC	WATT	HP
1	0.105	8484	11.4
0.75	0.079	6383	8.6
0.5	0.052	4201	5.6
0.25	0.026	2100	2.8

TIME for 100 m

MIN

30.1

40.2

60.2

120.5

TOTAL TIME

MIN

301

402

602

1205

assuming 1000 m straight line path

HRS

5.0

6.7

10.0

20.1

1 REV = $2\pi r$

$= 2\pi(0.529 \text{ m})$

$= 3.32 \text{ m}$

$\frac{r \omega}{\text{min}} = \frac{2\pi}{1 \text{ rev}} \cdot \frac{1 \text{ min}}{60 \text{ sec}}$

$\frac{\text{kN-m}}{\text{s}}$

MOTOR CALCULATIONS

DRUM TORQUE = 80.8 kNm

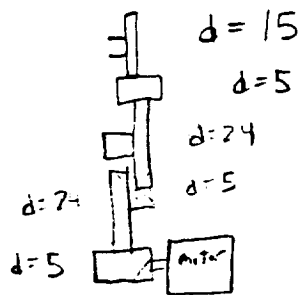
AFTER GEAR REDUCTION $80.8 \text{ kNm} (0.07) = 5.66 \text{ kNm}$

POWER $70 \text{ rpm} = 7,329 \frac{\text{rad}}{\text{s}} \times 5.66 \text{ kN.m} = 414.82 \text{ kW}$

$$= 55 \text{ hp}$$

27.5 hp PER MAIN DRIVE MOTOR

GEAR ANALYSIS



$$e = \text{Gear Ratio} = \frac{\text{driving}}{\text{driven}} = \frac{(5)(5)(24)(5)}{(24)(24)(5)(15)} = .07$$

$$n_{\text{last}} = e n_{\text{first}}$$

$$n_{\text{last}} = 0.07 (1000 \text{ rpm}) = 70 \text{ rpm}$$

TRANSPORT VELOCITY OF UNLOADED INCREMENT

$$V = RW \quad R = \text{WHEEL RADIUS} = 1.38 \text{ m}$$

$$V = 1.38 \text{ m} (70 \text{ rpm}) = 1.61 \text{ m/sec}$$

$$\text{TIME TO TRAVEL } 1000 \text{ m IN WHEEL MODE} \quad 1000 \text{ m} \times \frac{1 \text{ sec}}{1.61 \text{ m}} = 10 \text{ min}$$

VELOCITY OF SKID IN DRAGGING MODE

$$W = 70 \text{ rpm} \quad \text{average diameter of cable drum } 0.5 \text{ m}$$

$$V = rW = 0.5 \text{ m} (70 \text{ rpm}) = .58 \frac{\text{m}}{\text{sec}}$$

$$\text{TIME TO TRAVEL } 1000 \text{ m} \quad 28.57 \text{ min}$$

AUGER SPINNER

$$e = \text{GEAR RATIO} = \frac{(15)(10)(10)}{(24)(15)(5)} = \frac{100}{120} = 0.83$$

$$\text{shaft speed} \quad W = (.83)(500) = 415 \text{ rpm}$$

AUGER LIFTER

$$\text{MOVING UP AND DOWN} \quad \text{SHAFT GEAR RATIO } e = \frac{15}{10} = 1.5$$

$$W = 500 (1.5) = 750 \text{ rpm}$$

$$V = RW = .05 (750 \text{ rpm}) = 37.5 \frac{\text{m}}{\text{min}} = .625 \frac{\text{m}}{\text{sec}}$$

$$\text{TIME TO drill } 3 \text{ m} = \frac{3 \text{ m}}{.625 \text{ m/sec}} = 4.8 \text{ sec}$$

ENGINEERING CALCULATIONS

FORCE REQUIRED TO PULL HABITAT + SLED = 153 kN

SUPPORT LEGS

WORST CASE - ALL LOAD ON ONE LEG

MATERIAL - 6061-T6 AL YIELD STRENGTH = 276 MPa

$$\sigma_y = \frac{F}{A} \quad A = \frac{F}{\sigma_y} = \frac{153 \text{ kN}}{276 \text{ MPa}} = 5.5 \times 10^{-4} \text{ m}^2 = .859 \text{ in}^2$$

FROM MACHINERY'S HANDBOOK-p217 $\Rightarrow$ ALUMINUM I-BEAMS

SMALLEST I-BEAM 3x25" AREA = 1.392 in²
(8.9 x 10⁻⁴ m²)

BACK SOLVING USING THIS BEAM SIZE $F = \sigma A = 276 \text{ MPa} (8.9 \times 10^{-4})$
= 247 kN

SMALLEST AVAILABLE BEAM ABLE TO HOLD

WORST CASE LOAD + 94 kN

DRILLS

WORST CASE ALL LOAD ON 1 DRILL IN SHEAR

6061-T6 ALUMINUM SHEAR STRENGTH = 206 MPa

$$A = \frac{F}{\sigma_s} = \frac{153 \text{ kN}}{206 \text{ MPa}} = 7.43 \times 10^{-4} \text{ m}^2 = 1.15 \text{ in}^2$$

CROSS SECTION OF DRILL SHAFT MUST BE AT LEAST 7.43 x 10⁻⁴ m²

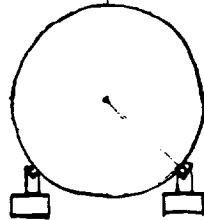
$$A = \pi R^2 \quad R = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{7.43 \times 10^{-4} \text{ m}^2}{\pi}} = .015 \text{ m}$$

DRILL SHAFT MUST HAVE RADIUS OF .015 m

- ✓ 1. SIZE FRONT & REAR BRACE
- ✓ 2. DRAW FRONT BRACE CONNECTION
- ✓ 3. SIZE FRONT SCREWS
- ✓ 4. DRAW HARDPOINT CONNECTION
- ⑤ CHECK TIRE RESISTANCE (?)
- 6 RE-SIZE EVERYTHING (SCREWS, ETC)
- 7. NEW WEIGHT ESTIMATE

MODULE: 183,750 N (MILS)
 EACH PAIR OF SUPPORTS TAKE 5
61250 N (MILS) STRAIGHT DOWN
SUPPORTS ARE .73m LONG X .11 X .11m

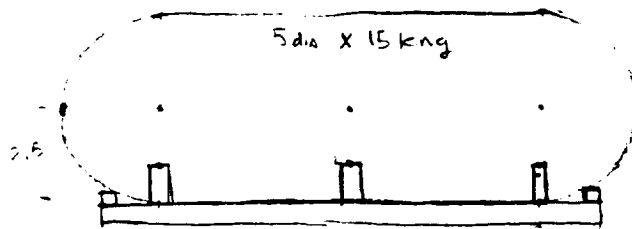
REAR BRACE:



BEST CASE: ASSUME FULL MODULE
 WEIGHT TAKEN AS A MOMENT
 (COMPENSATES FOR 45° SIDEHILL
 WITH SMALL SHOCKS (SUDDEN LOADS))
 SO MOMENT IS

$$\frac{(183,750)(.73)}{2} = 67068.75 \text{ N}\cdot\text{m}$$

EACH BRACE (FRONT &
 REAR) TAKE HALF LENGTH OF
 SUPPORT



M (REAR BRACE) REACTION
 MOMENT

$$M = 67068.75 \text{ N}\cdot\text{m}$$

$$\delta_x = \frac{My}{I}$$

IF REAR BRACE IS .11 X .11m, $y = .055$, $I = \frac{bh^3}{12} = .0000122$

$$\delta_x = \frac{(67068.75)(.055)}{.0000122} = 302338467.3 \text{ N} \quad \text{TOO HIGH!}$$

TRY .12m X .12m

THEN $y = .06$, $I = \frac{bh^3}{12} = .00001728$

$$\delta_x = \frac{My}{I} = 232877604.2 \text{ N}$$

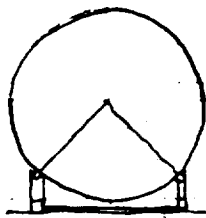
FINE.

REAR BRACE IS .12 X .12m CROSS SECTION
 ($y = .06$, $I = .00001728$)

ASSUME SAME FOR FRONT

RAISING MODULE TO FIT FRONT BRACE UNDER INCREASES MOMENT ON
 ON BRACES.

RAISE MODULE BY .25m (SUPPORT IS .73 m LONG)



$$\text{NEW MOMENT IS } (.73\text{m} + .25\text{m}) \left(\frac{183,750}{2} \right) =$$

$$= (.98\text{m})(91875\text{N}) = 90037.5$$

TRY .15 X .15m BEAM: $y = .075$, $I = \frac{bh^3}{12} = .000042$

$$\delta_x = \frac{My}{I} = 160781250 \text{ N}$$

UNDERSTRESSED.

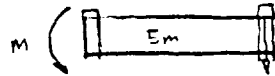
ORIGINAL PAGE IS
 OF POOR QUALITY

TRY $.14 \times .14$: $y = .07$, $I = .000032$ $\delta_y = \frac{m y}{I} = \frac{(90037.5)(.07)}{.000032} = 196957031.25$
 REF-TEK

BRACES ARE $.14 \times .14$ m

SUPPORTS ARE RAISED FROM .73 TO .98 m LONG

FRONT (& MAYBE REAR) BRACE REMOVABLE CONNECTION:



$M = 67068.75 \text{ Nm}$ "WELD" FORCE = $\frac{67068.75 \text{ Nm}}{5 \text{ m}} = 13413.75 \text{ N}$

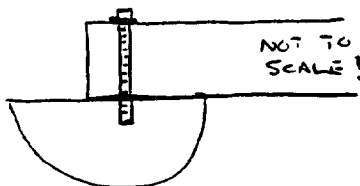
CHECK THAT REAR BRACE ALONE CAN TAKE MOMENT WHEN FRONT IS REMOVED

SIZE CAP-SCREW: $P_a = \frac{N}{m^2}$ $N = 13413.75 \text{ N}$

CAP-SCREWS ARE M10 X 1.5 FINE PITCH 8.8 PROPERTY CLASS

THESE ARE RIDICULOUSLY OVER-SIZED BUT I DON'T HAVE TIME TO REINVENT THE CAP-SCREW. THESE ARE STEEL, TI WOULD PROBABLY BE BETTER.

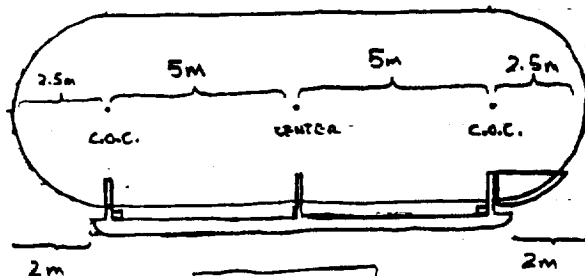
BRACES (BOTH) ARE BOLTED DOWN WITH ONE (ABOVE SPECIFIED) CAP SCREW AT EACH END. BRACES ARE PLACED AGAINST THE SUPPORT BOTTOMS



CAP SCREWS ARE $\approx .18$ m LONG SO AS TO EXTEND ≈ 3 cm INTO THE SKI.

SKIDS ARE ≈ 11 m LONG

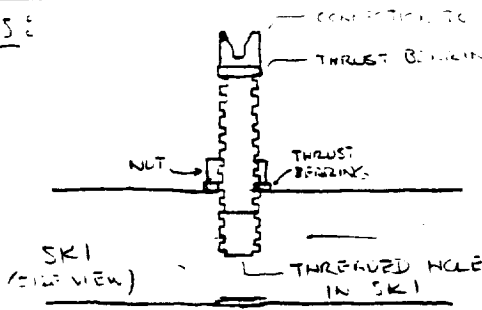
SUPPORTS ARE 5 m APART



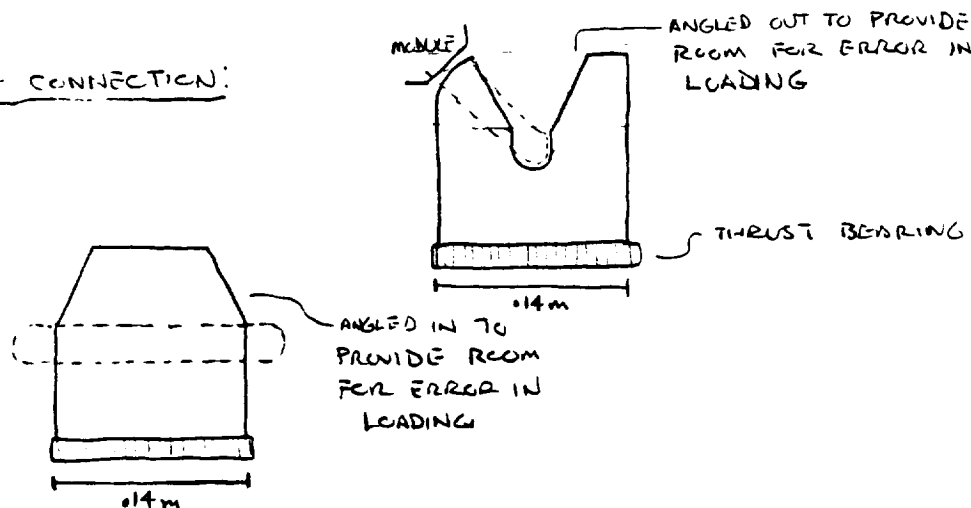
CLOSE TO SCALE

UNUSUAL PAGE IS OF POOR QUALITY

POWER SCREWS/SUPPORTS:



CLOSE-UP OF CONNECTION:



* SPECIFY LOADS THAT HARD POINT MUST BE ABLE TO TAKE!

POWER SCREW: $I = \frac{\pi r^4}{4} = \frac{\pi d^4}{64}$ FOR SOLID CYL.

FOR SCREW, USE UNTHREADED DIAMETER FOR d

$$\sigma_y = \frac{MY}{I} \quad y = r, \quad M = (61250 \text{ N})(\text{LENGTH})$$

LENGTH = TRAVELLING HEIGHT = .98 m

$$M = (61250 \text{ N})(.98 \text{ m}) = 60025 \text{ N}$$

$$\sigma_y(\text{YIELD}) = 270 \text{ MPa}$$

$$\sigma_x = \frac{(60025) y}{I}$$

TRY .15 DIA, .075 r, $y = .075$

$$I = .000025$$

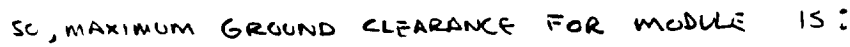
$$\sigma_y = 180 \text{ MPa}$$

THIS WILL WORK WITH 6061 T6 ALUM!

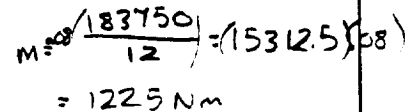
CAN I MAKE SKI + SCREW (MIN) < .73 m?

42.381	50 SHEETS	5 SQUARE
42.382	100 SHEETS	5 SQUARE
42.389	200 SHEETS	5 SQUARE

www.usa



∴ MINIMIZE CONNECTION CLEARANCE; WHICH DOESNT ALLOW FOR ANY ROOM FOR ERROR.



$$200,000,000 = \frac{1225}{1} Y$$

$$I = \frac{\pi r^4}{4} \quad y = r$$

$$\frac{I}{Y} = \frac{\pi r^3}{4} = \frac{\pi r^3}{4} = \frac{1225}{200,000,000} \Rightarrow \pi r^3 = \frac{4900}{200,000,000} \cdot \frac{49}{200,000,000}$$

$$r^3 = \frac{.0000245}{\pi} = 7.8 \times 10^{-6}$$

$$d = .04 \text{ m}$$

A hand-drawn technical sketch of a structural connection between a column and a beam. The column is represented by a vertical rectangle with diagonal hatching. The beam is shown as a horizontal structure at the top, with a curved section indicating a joint. A curved arrow points downwards from the beam, suggesting a load or movement. To the right of the column, there are two vertical dimension lines. The first dimension line is labeled $.05W$. The second dimension line is labeled $.01W$ THRUST BEARING. Below these dimensions, there is a rectangular box containing the text "CONNECTION CLEARANCE: 1".

ORIGINAL PAGE IS
OF POOR QUALITY

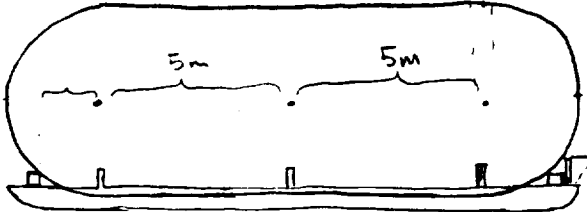
DEPTH OF SCREW TO REMAIN IN SKI: .15 m (NO GOOD REASON)

SO MAX GROUND CLEARANCE IS:

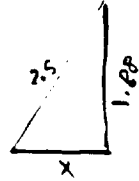
$$(\text{DEPTH OF SKI}) - (.04 + .15)$$

IF SKI IS .3m DEEP (= 1 FOOT)

$$(.3) - (.19) = .11 \text{ m } (\approx 4.33 \text{ IN})$$

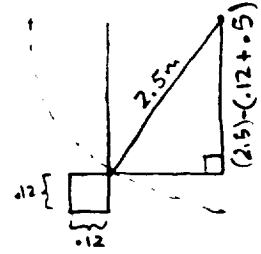


ASSUMPTION:
THERE WILL BE
A RADIAL BAND
AT THE END OF
THE STRAIGHT
SECTION.

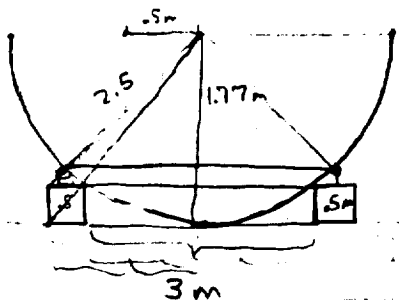


$$6.25 - (1.88)^2 = x^2$$

$$x = 1.65$$



SUPPORTS MUST BE

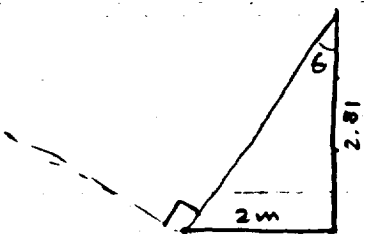


CROSS BRACES ARE
3.5 m LONG

SKIS ARE 15 m LONG

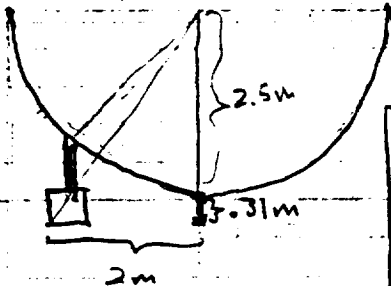
IF SKI IS .5 m DEEP (20 INCHES)
CLEARANCE IS .31m (12.2 INCHES) [BETTER]

SIDEHILL STABILITY: FULLY RAISED:



$$\theta = \tan^{-1} \frac{2}{2.81}$$

$$= 35.14^\circ$$



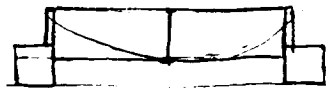
$$2.5 + .31 = 2.81$$

WITH SCREWS FULLY
EXTENDED, CAN
TAKE 35°
SIDEHILL

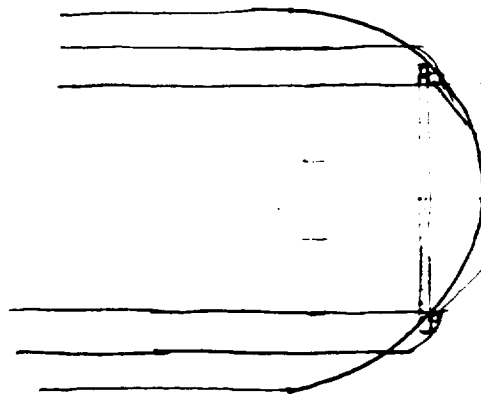
FRONT CONNEX

TOP OF SKI FOR
UNLOADING

TIP OF SKI
DURING
TRANSIT



ENTIRE FRONT IS REMOVED (NOT SWUNG
OPEN) EITHER AS ONE OR
TWO PIECES (ONE, PREFERABLY)

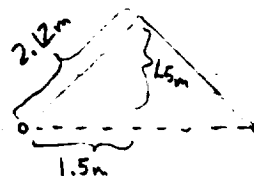


FRONT:



PINS EXTEND INTO
FRONT OF SKIS
PINS ARE .7m LONG BY .1m DIAMETER.

DOORS ARE .02 M
THICK



SCURRY GRAHAM, I JUST DONT KNOW HOW TO DRAW THIS
REAL WELL;

CABLES WILL ATTACH TO FRONT CROSS BRACE INSTEAD OF
DOORS.

CABLE TENSION
153 KN
SPLIT BETWEEN 2
CABLES

NEW PARTS LIST:

(2 ROLLIN W/ 14 FT.)

PARTS

SKIS (2): $(14.5m \times .5 \times .5)(2) =$

2(3.625)

TRC SQUARE



2(1.8125)

HALF SQUARE



2(1.42)

HALF CYL



= 2.847

CROSSBRACES (2): $(3.5m \times .12 \times .12)(2) = .1008m^3$

CAP SCREWS (4):

WASHERS (4):

1.8125 + 1.4235

3.24

JACKS/SUPPORTS

SCREWS (6): $(6)(.15 \text{ DIA} \times .54 \text{ L}) = .057m^3$

NUTS (6):

THRUST BEARINGS (12):

CONNECTIONS (6):

"DOORS" (1) $(.02 \times 4.24 \times .5m) = .0424m^3$

3.825 m³

6061 T6 ALUMINUM

= 2700 kg/m³

600 lbs

153 kg

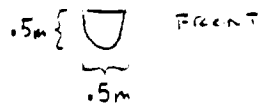
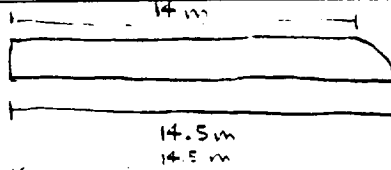
10,327.5 kg

OR 10.3 METRIC TONS

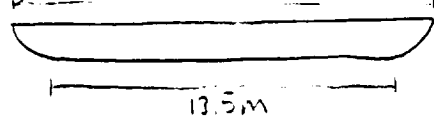
OR 20% OF
MODULE WEIGHT.

SKIS:

TOP

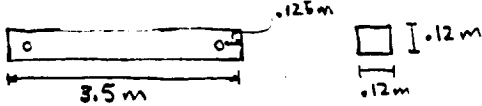


SIDE:

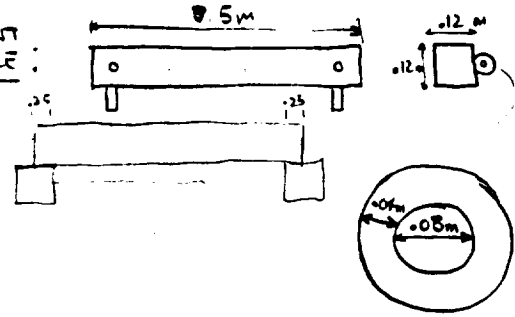


CROSS BRACES:

REAR BRACE:



FRONT BRACE:

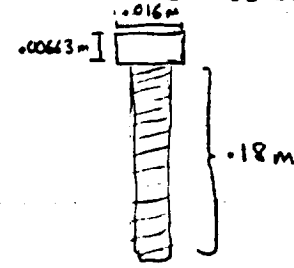


NOTES: 2 0.01m HOLES ARE DRILLED ALL THE WAY THRU, CENTERS OF HOLES .125m FROM BEAM ENDS

FRONT BRACE IS IDENTICAL EXCEPT FOR 2 CONNECTION EYES IN LINE WITH HOLES,

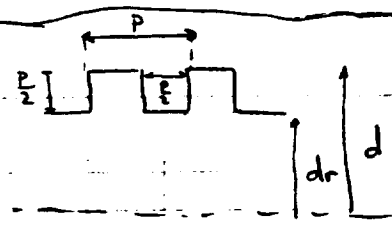
HOLES ARE FILLED BY HEX HEADED M10 X 1.5 FINE PITCH 8.8 PROPERTY CLASS STEEL CAP SCREWS

WHICH ARE .18m LONG (SEE 4180 BOOK FOR ALL SPECS)

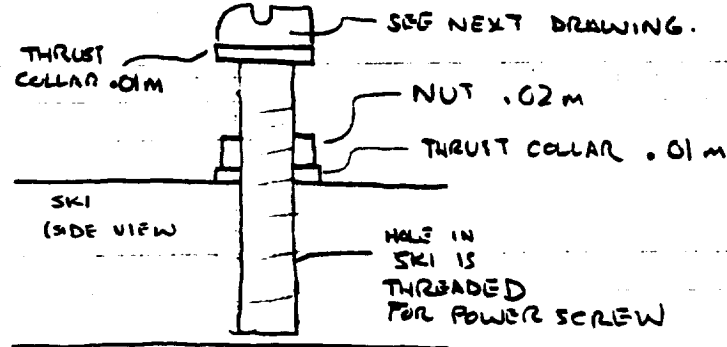


POWER SCREWS:

SQUARE THREAD POWER SCREW



$d = .2m$
 $dr = .15m$
 $P = .025m$



CHECK NUMBER 25 CN:

CONNECTION

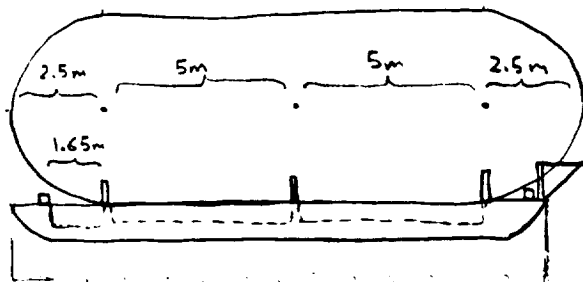
JACKS & NUTS (POWER SCREW DIAMETER)

THRUST BEARINGS

CABLE CONNEX.

REMINDE GRAMAM ABOUT CABLE GUIDES.

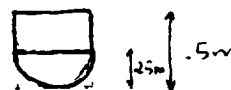
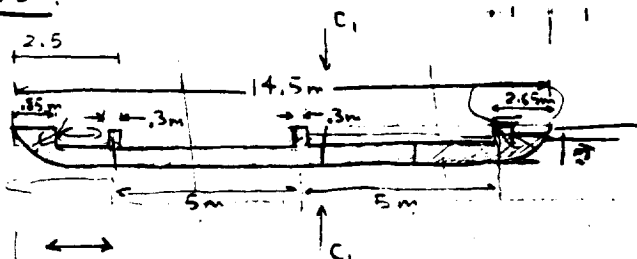
.06



1 SQUARE = .5m

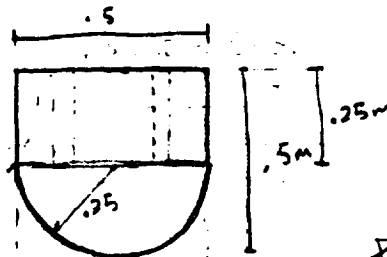
SKIDS ARE CUT OUT BETWEEN SUPPORTS

SKIDS:



2.45
.85
3.40

CUT AT C₁



FIND PSI ON SKIS

NASA'S MAIN QUESTIONS

1. WEIGHT
2. ENERGY
3. TIME
4. EVA (ASTRONAUT INVOLVEMENT)
5. MAINTENANCE, SPARES

JOYCE/DAYTON CORP.
LOOK AT

TALK GENERALLY ABOUT
PERFORMANCE & LIMITS
UPHILL, DOWNHILL, SIDEHILL,

SURFACE MODELS OF MARS (GB 641.052X 1975)

SOIL DENSITY: 1.2 g/cm³ (USE 1.2?)

BEARING: 3.5 N/cm²

PENETRATION RESIST: 4.0 N/cm²/cm VIRGIN
5.2 N/cm²/cm PACKED (LUNAR ROVER TRACK)

$$\text{BEARING} = 3.5 \text{ N/cm}^2$$

$$\begin{aligned} \text{MODULE} + \text{SKID} &= 183750 \text{ N} + (10,327.5 \text{ kg}) \left(9.81 \frac{\text{m}}{\text{s}^2} \right) \\ &= 183750 \text{ N} + 37954 \text{ N} \\ &= 221704 \text{ N} \end{aligned}$$

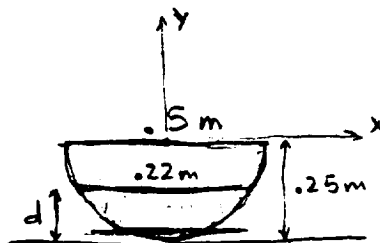
$$\text{SKI AREA (LARGEST CASE)} = 2(14.5 \times .5) = 14.5 \text{ m}^2$$

$$\frac{14.5 \text{ m}^2}{1} \times \frac{10000 \text{ cm}^2}{1 \text{ m}^2} = 145000$$

$$\frac{221704}{145000} = 1.53$$

$$\begin{aligned} \text{SOIL BEARING} &= 3.5 \text{ N/cm}^2 = \frac{221704 \text{ N}}{2(14.5 \times 10000)} \\ &= \frac{221704 \text{ N}}{(14.5)(3.5)(20000)} \end{aligned}$$

$$x = .22 \text{ m}$$



$$x^2 + y^2 = .25^2$$

$$y^2 = .25^2 - x^2$$

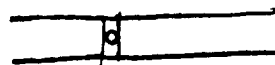
$$y = \sqrt{.25^2 - x^2} \quad x = .11$$

$$\begin{aligned} x^2 + y^2 &= .25^2 \quad y = .22 \\ \text{DISTANCE SUNK IN} &= Q : Q = .25 - y \\ &= .25 - .22 \\ &= .03 \text{ m} \end{aligned}$$

MODULE WILL SINK IN .03 m (3cm, OR 1.2 IN)

AT MOST

(I THINK)



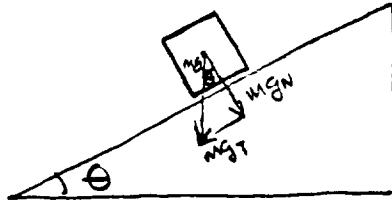
PERFORMANCE OF SKID : CURRENTLY TAKES $\approx 35^\circ$ SIDESLIP WITHOUT TIPPING

DOWNHILL : COEFFICIENT OF FRICTION = .3 TO .7 = μ

$$\mu = \frac{F}{N}$$

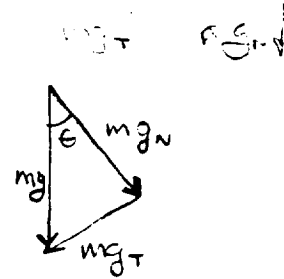
$$F = \mu N$$

WHAT ANGLE CAUSES SLIDING?



$$mg_N = mg \cos \theta$$

$$mg_T = mg \sin \theta$$



$$mg_T = F$$

$$mg_N = N$$

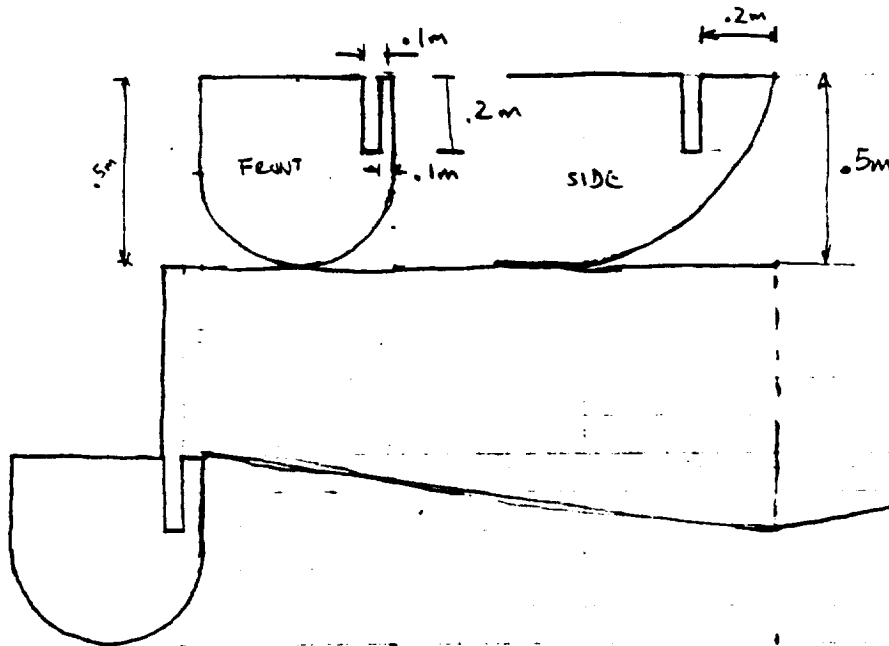
AT CRITICAL ANGLE

$$mg \sin \theta = \mu mg \cos \theta \quad \mu = \frac{\sin \theta}{\cos \theta} = \tan \theta$$

$$\mu = .3 \text{ TO } .7$$

$$\theta = \begin{cases} \tan^{-1}(.3) = 17^\circ \\ \tan^{-1}(.7) = 35^\circ \end{cases}$$

SKID WILL BEGIN SLIDING DOWN-HILL
BETWEEN 17° & 35° DEPENDING ON μ



ORIGINAL PAGE IS
OF POOR QUALITY

HOW BIG A ROCK CAN THE GATE PUSH?

$$\delta_x = \frac{My}{I}$$

$$\delta_x = 270,000,000 \text{ Pa}$$

$$I = \frac{\pi r^4}{4} = \frac{\pi d^4}{64}$$

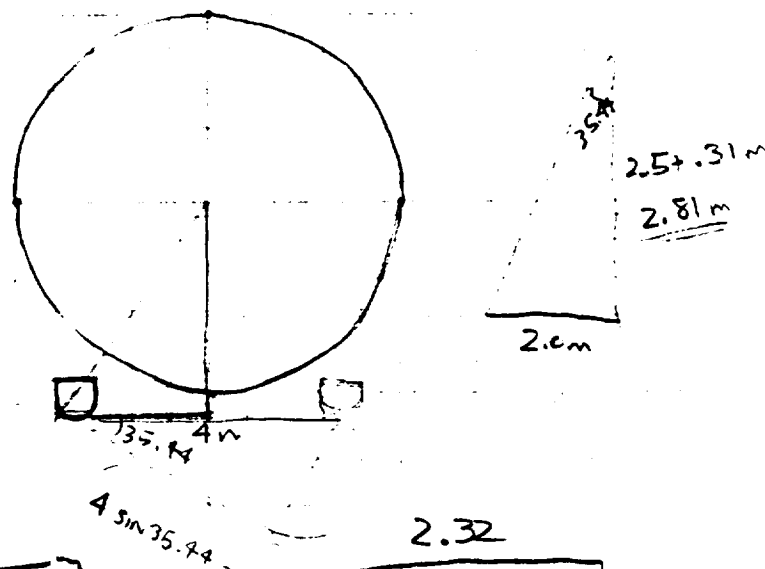
$$r = .05 \text{ m} \quad y = .05 \text{ m}$$

$$M = \frac{I \delta_x}{y} = \frac{\left(\frac{\pi r^4}{4}\right) (270,000,000)}{.05} = \frac{\pi r^3 270,000,000}{4}$$

$$M = 26507.2 \text{ Nm}$$

PIN CAN TAKE 26500 Nm
OR 53014 N AT TOP

HOW BIG A ROCK CAN ONE SKI GO OVER W/OUT TIPPING



SKID CAN TAKE A 2.3 m ROCK UNDER ONE SKID WITHOUT TIPPING

ORIGINAL PAGE IS
OF POOR QUALITY

CABLE CONNECTIONS

CABLE TENSION: 153 KN SPLIT BETWEEN 2 CABLES

FORCE PER CONNECTION: 76500 N

AREA: πr^2 $r = .02m$

$$\frac{270,000,000 \text{ N}}{m^2} \times .00126 = 339,292 \text{ N}$$

SHOULD BE ABLE TO
HOLD IT

LOWER DOOR TO GIVE A MARGIN OF SAFETY ON
SLIDING ROCKS

POWER SCREW WEIGHT ESTIMATE:

MODULE (MARS) 183,750 N $\Rightarrow$ 30,625 N ON EACH JACK

$$F = ma \quad 30,625 = (m) \left(9.8 \frac{m}{s^2} \right) = 3,125 \text{ kg (EARTH)}$$

$$1 \text{ PND} = .4536 \text{ kg}$$

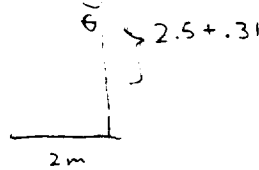
$$3,125 \text{ kg} \times \frac{1 \text{ PND}}{.4536 \text{ kg}}$$

6889.33

NUMBERS TO RUN:

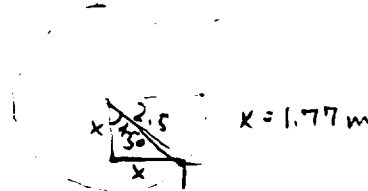
- ✓ ① FORCE ON DOOR
- ✓ ② MAX MOMENT & AXIAL ON JACKS
- ✓ ③ POWER HEAD: MAX SIDE & FORWARD

FORCES ON JACKS:



$$\theta = \tan^{-1}\left(\frac{2}{2.81}\right) = 35.44$$

35.44° SIDEHILL STABILITY



SCREW HEIGHT (MAX EXTENSION) = .54m

EACH JACK TAKES: $\frac{183750 \text{ N (MARS)}}{6} \leftarrow \frac{(\text{TOTAL MOD. FORCE})}{\# \text{ OF JACKS}} = 30625 \text{ N (MARS)}$
(AXIAL)

BENDING MOMENT: ON 35° SIDEHILL, BENDING IS MAX. ASSUME JACKS TAKE FULL MOD. MASS (TO COMPENSATE FOR SMALL SHOCK LOADING (IMPACTS))

TOTAL MODULE IS SUPPORTED BY 3 JACKS ON SIDEHILL $\Rightarrow \frac{183750}{3} = 61250 \text{ N (PER JACK)}$

JACK LENGTH (FULL EXTENSION): .54m

MAX. BENDING MOMENT = 33075 NM

IF POWER SCREW IS TITANIUM ALLOY: YIELD $\approx 760 \text{ MPa}$

$$\delta_x = \frac{m y}{I} \quad m = 33075 \text{ N}\cdot\text{m} \quad y = r \quad I = \frac{\pi r^4}{4}$$

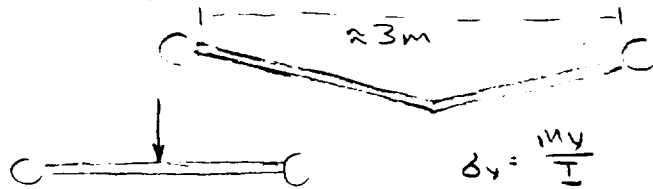
$$\delta_x = 760,000,000 \frac{\text{N}}{\text{m}^2}$$

$$\delta_x = m \left(\frac{4r}{\pi r^4} \right) = m \frac{4}{\pi r^3} \quad r^3 = \frac{m 4}{\pi \delta_x} = \frac{132,300}{2387610000} = .554 \times 10^{-5}$$

$r = .04 \text{ m}$

UNTHREADED DIA. OF TI ALLOY POWER SCREW = .08 m

FORCES ON THE GATE:



$$\delta_y = \frac{my}{I}$$

$$I = \frac{bh^3}{12}$$

$$270,000,000 = \frac{my}{I}$$

$$h = .02$$

$$b = .3$$

$$y = .01$$

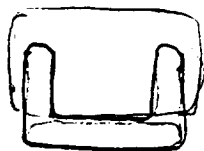
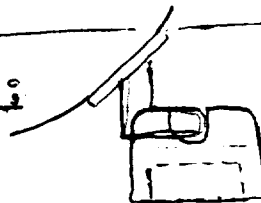
$$54 = my$$

$$M = 5400 \text{ N m}$$

$$\frac{M}{1.5m} = 3600 \text{ N (MAX FORCE AT CENTER)}$$

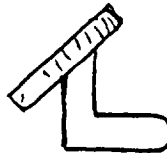
GATE CAN TAKE 3600 N (HORIZONTAL) AT CENTER BEFORE YIELDING

HARD POINT CONNECTION:



SIDE (OF HABITAT) VIEW

MODULE HARDPOINT:



END (OF HABITAT) VIEW

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OF POOR QUALITY

RecommendationsMaterial
Aluminum 6061 T6Skeleton Structure:

Nominal Pipe Size 2 in #80 - heavy duty

OD - 2.375 in

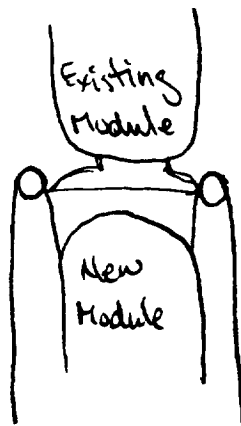
ID - 1.939 in

Wall thickness = 0.218 in

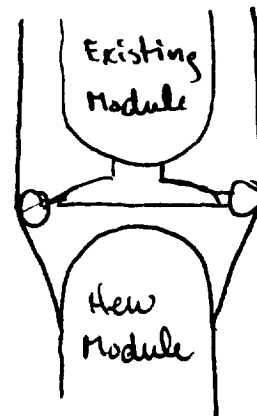
p. 8-196 Mark's Handbook

Pulley / wheel:

Configuration #1



Configuration #2



← Better method to align new module. More compressive forces.

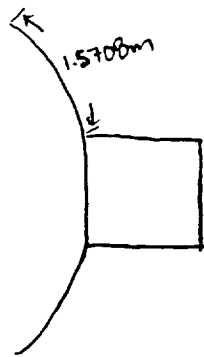
Pulley structure has to withstand

① 155 kN at configuration #1

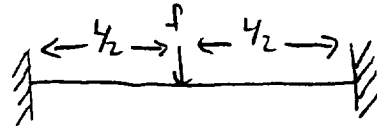
② < 153 kN at configuration #2

Also, in configuration #2, cone is pressed against Existing module for better hold.

Recommended Pulley wheel size = 0.16 m - diameter.

Bending

Model curve part as a beam with fixed ends.



Shisky and Mischke
p. 741

Maximum Deflection:

$$y_{\max} = - \frac{F l^3}{192 E I}$$

$$I = 3.6119 \times 10^{-7} \text{ m}^4$$

$$E = 71 \text{ GPa} \text{ - material}$$

$$l = 1.57 \text{ m} \text{ - estimate}$$

$$y_{\max} = - \frac{(F)(1.57 \text{ m})^3}{(192)(3.6119 \times 10^{-7} \text{ m}^4)(71 \text{ GPa})}$$

$$y_{\max} = (F)(7.86 \times 10^{-7} \frac{\text{m}}{\text{N}})$$

Using max force for column bending,

$$F = 1000 \text{ kN}$$

$$y_{\max} = (1000000)(7.86 \times 10^{-7} \frac{\text{m}}{\text{N}})$$

$$= 0.786 \text{ m}$$

$F = 1000 \text{ kN}$ - overestimate

$$\text{for } y_{\max} = 0.01 \text{ m}, F = 12,700 \text{ N or } 12.7 \text{ kN}$$

$$12,700 \text{ N} = (\text{mass of skid + module})(\text{acceleration})$$

$$12,700 \text{ N} = (65,000 \text{ kg})(a)$$

$$\therefore a = 0.1957$$

← As assume, acceleration will be very small. On the magnitude of $\frac{1}{10}$ of a .

Column Compression

Shisley and Mischke p. 123



Force at which module have direct impact
on a column of the support

$$P_{cr} = \frac{4\pi^2 EI}{l^2}$$

l = length of pipe

E = modulus of Elasticity

$$P_{cr} = \frac{(4)(\pi^2)(71 \text{ GPa})(3.619 \times 10^{-7} \text{ m}^4)}{(1 \text{ m})^2}$$

$I = Ak^2$ A = Cross-section Area

k = Radius of Gyration

$$= 1012403 \text{ N}$$

Assumption: Both end fixed

$$\cong 1000 \text{ kN}$$

$$A = 0.0009529 \text{ m}^2 \quad \left. \begin{array}{l} \\ \\ \end{array} \right\} = 3.6119 \times 10^{-7} \text{ m}^4 = Ak^2$$

$$k = 0.0194691 \text{ m}$$

+ BATTERY WEIGHT